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A comprehensive index to assess the sustainability of water and sanitation management systems

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ABSTRACT

A comprehensive sustainability index for the assessment of water and sanitation management systems (WSMS) is presented. The index was based on a conceptual framework that perceives sustainability as a combination of territorial, temporal, and personal aspects. A set of sustainability indicators was selected in agreement within this framework, and the 'Water and Sanitation Sustainability Index' (WASSI) was built. The WASSI was used to assess the sustainability of the WSMS of the city of Salta, Argentina. Indicators were calculated from information gathered by several means including literature reviews, questionnaires, visits, and participatory workshops. The index was sensitive to detect variations between different aspects of the local WSMS. It was also relatively independent to the quantity and quality of the information available. The WASSI could be a useful tool to assess and improve sustainability of water and sanitation throughout the management systems.

Key words | Argentina, management systems, Salta, sanitation, sustainability, water

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INTRODUCTION

Through the 'Millennium Development Goals' (MDGs), all United Nations member states have pledged, amongst other things, to reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. Despite the fact that some good practices have emerged from recent water and sanitation access projects, there is still much to be done to achieve this goal (UNDP 2010). But what does 'sustainable' access really mean? The concept of sustainable development was launched to balance 'economic and social systems and ecological conditions' (WCED 1987) and is often represented with the 'triple bottom line' of economy, environment, and society (Elkington *et al.* 2007). In spite of its seemingly universal acceptance, the idea of sustainable development has contradictions and limitations that reduce its usefulness in concrete situations (Escobar 2001). As extensively discussed in Seghezzo (2009), particularly contentious are its excessive anthropocentrism and heavy reliance on conventional (neoclassic) economic reasoning.

'Sustainability' is often considered a synonym of 'sustainable development'. Yet some fundamental distinctions between these two have been identified (Dresner 2002). In particular, it has been argued that the notion of sustainability should not be exclusively linked to economic growth and must be more adaptable to each particular location or 'place', where explicit acknowledgment and revaluation of local cultures and worldviews becomes possible (Macnaghten & Urry 1998; Escobar 2001). It has also been said that the strong temporal components of most environmental problems are not explicitly recognized in the conventional triple bottom line despite all the rhetoric about inter-generational justice (Adam 1998). Sustainability can also be seen as the result of the combined attitudes, feelings and behaviors of individuals. Studies indicate that personal happiness is relatively independent from economic, environmental, and even social aspects (Marks *et al.* 2006; O'Neill 2008). Furthermore, as discussed in Dryzek (1987), only individuals, with

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their morals and values, can achieve the 'change of consciousness' needed to achieve an ecologically 'rational' world. It can be argued that the triple bottom line approach can barely account for some of the personal aspects of development, as discussed in McShane (2007). The complex spatial, temporal and personal links between nature and culture make any attempt to arrive at a single, worldwide definition of sustainability futile. Each location requires its own, context-dependent meaning of sustainability, which should not only be theoretically coherent and comprehensive but also useful for solving specific environmental and social problems.

Indicators and indices play an important role in measuring, assessing, and informing the extent to which we move toward sustainability (Molle & Mollinga 2003; Ness *et al.* 2007; Kajikawa 2008). However, indicators must meet a number of basic criteria for them to be truly *sustainability* indicators (Valentin & Spangenberg 2000; Starkl & Brunner 2004; Bell & Morse 2008; Van de Kerk & Manuel 2008). First of all, indicators have to be as simple, relevant and sensitive as possible to the variables and trends that are relevant for sustainability. They also need to be measurable and relatively independent from each other, although some redundancy might enhance the robustness of the assessment. Data needed to estimate the indicators must be readily available, reliable, and as recent as possible. In all cases, it seems indispensable that indicators and indices are rooted on a conceptual framework agreed upon for each situation. It is important to note that the feasibility and affordability of the entire assessment also depends on the number and complexity of indicators we intend to measure (Bossel 1999).

Indicators have also been used to assess water and sanitation management systems (WSMS) (Brunner & Starkl 2004; Sternlieb & Laituri 2010; Brown & Matlock 2011). These complex systems require dynamic, integrated, participatory, and adaptive management strategies (Bertrand-Krajewski *et al.* 2000) in which multiple uses and users are taken into consideration simultaneously (Berger *et al.* 2007). In practice, however, WSMS have historically been rather simplistic, static, fragmented, and governed by short-term sectoral interests (Pahl-Wostl *et al.* 2008). The importance of indicators as incentives for a deep and permanent debate on water and their role in site-specific water resources planning processes has been highlighted by Molle & Mollinga (2003). They provided a critical examination of the virtues and shortcomings of water indicators, including the so-called Water Poverty Index (WPI). The WPI (Lawrence *et al.* 2002; Sullivan 2002) is based on a methodology comparable to that of the Human Development Index (HDI) developed by the United Nations (UNDP 2009). The WPI has been built on five components: (1) Resources; (2) Access; (3) Capacity; (4) Use; and (5) Environment. Proponents of the WPI claim that this index can compare the performance in the water sector across countries in a holistic way and provide 'a measure of water availability and access that is adjusted by socio-economic and environmental factors' (Lawrence *et al.* 2002: 10). The WPI provides an interesting worldwide comparison of water accessibility and can be a platform for the development of case-specific water scarcity assessment indices. This conceptual framework was based on a 'consensus of opinion from a range of physical and social scientists, water practitioners, researchers and other stakeholders'. It could be argued that this agreement, desirable as it might be, does not necessarily mean that 'all the relevant issues were included in the index', as claimed by Lawrence *et al.* (2002: 1), or that the index is sufficiently 'holistic' (Sullivan *et al.* 2003: 189) or 'integrated' (Sullivan 2002: 1195) as to be applicable everywhere. Therefore, whether the WPI can be used to assess the *sustainability* of WSMS in specific settings remains to be seen.

In this paper, we present results from a research project that aims to contribute to the delineation of a sustainability assessment method for urban and peri-urban WSMS. The project has been organized around three main action lines: (a) adoption of an inclusive conceptual framework for analyzing sustainability issues at local level; (b) selection, adaptation and/or development of a decision-making methodology based on sustainability indicators that could be applied within this framework; and (c) application of this methodology for the assessment of the sustainability of a specific WSMS. It is our contention that a thorough discussion around the concept of sustainability and its adaptation to specific problems and settings can assist policy-makers to establish the WSMS of the future. By assessing real case studies we expect to validate the conceptual framework and contribute to the attainment of more sustainable water resources management in the region.

MATERIALS AND METHODS

The case study

The case study selected was the city of Salta, capital of the Province of Salta, in northern Argentina. According to recent estimates, the population in the city is more than 500,000 (INDEC 2010). In Salta, the provision of drinking water and sanitation went through a series of institutional changes in recent years. The service was provided by state agencies until 1998. During the privatization process that took place in the country during the 1990s, the service was handed over to the private sector. With the exception of a few towns, the entire provincial territory, which spans an area of more than 150,000 km^2, was given in concession to one single company. The experience was not as expected and the governance and equity of the water management system came under scrutiny. Especially questioned were their inability to provide good-quality services to marginal areas and their fixation with profit. Similar criticisms of the ability of private companies to adequately manage water and sanitation services were raised in other parts of the country (Azpiazu et al. 2005). In May 2009, following a trend that had started in the federal capital (Buenos Aires), the provision of such services in Salta reverted back to a (partly) state-owned company. The provincial government explicitly held in reserve the right to re-privatize the company if considered necessary by reasons of 'opportunity, merit, or convenience' (Provincial Law 7571/2009, article 5). Two years have passed but is still too early to judge whether the new ownership scheme is really addressing the problems that led to the 're-provincialization' of the water company.

A scheme of the water and sanitation system in Salta is depicted in Figure 1. About 65% of the water for human consumption, industrial activity, and some urban and peri-urban agriculture is extracted from more than 150 wells distributed around the city. The remaining comes from surface water captured either directly from rivers or indirectly through

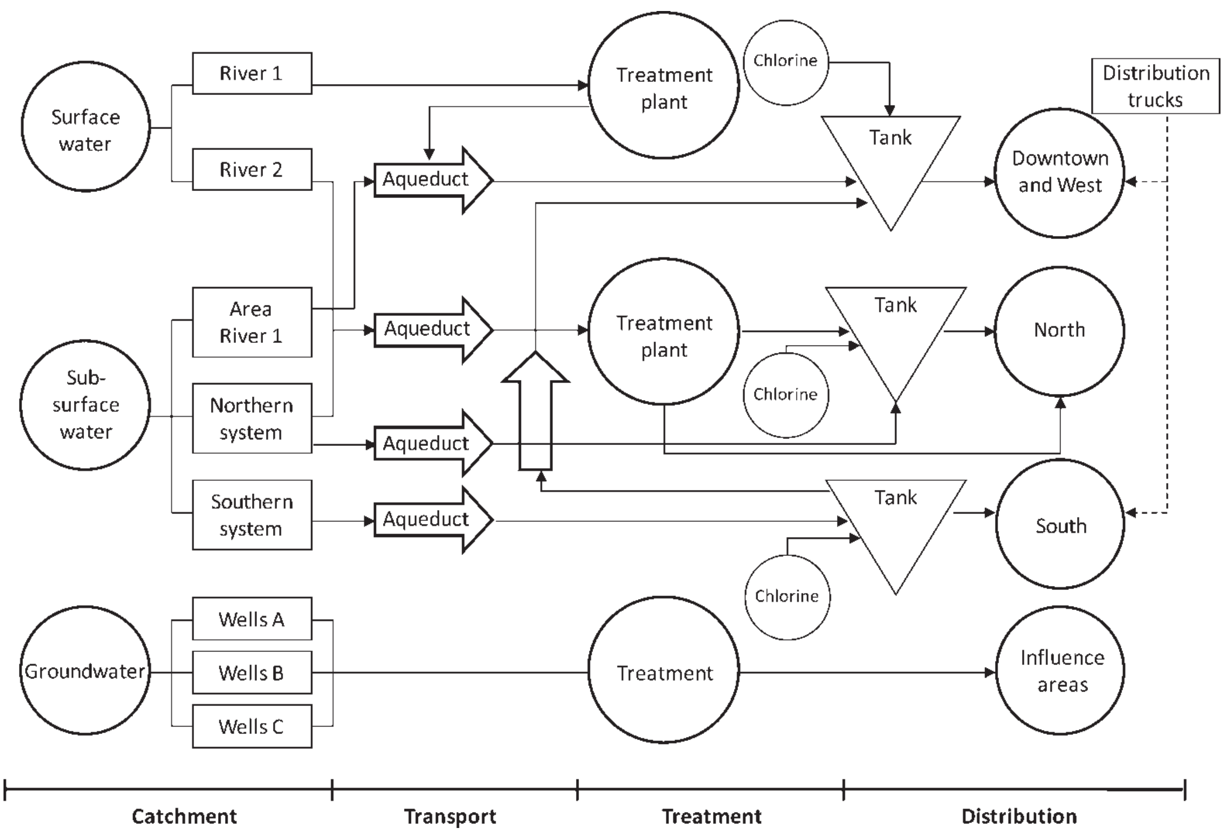

Figure 1 | Main stages of the water and sanitation management system (WSMS) in Salta, Argentina.

shallow drains located close to water courses. This water is later conveyed to the city by way of closed aqueducts. According to our estimates (based on data provided by the provincial Secretary of Water Resources), *per capita* water availability is more than 600 L/p.d, although unplanned urban growth is constantly putting increasing pressure on the water system. Water from aqueducts is transported to a centralized potabilization plant from where drinking water is distributed to the entire city, whereas water from the wells is generally subject to a chlorination process and injected directly into the network. Sewage is collected through a sewerage network designed to be separated from urban runoff although illegal connections between these two systems are common. Collected sewage is conveyed and treated in two main treatment plants. The southern and main section of the city is served by a system of trickling filters. Northern neighborhoods treat their sewage in outdated, ill-maintained waste stabilization ponds (a new system is currently under construction). Treated effluents are generally discharged into rivers. Several discharges of raw sewage into the city's rivers can still be detected, and activities of reuse of raw or treated sewage are scarce and informal.

Conceptual framework

The notion of sustainability applied to this case study was the 'five-dimensional' scheme proposed by Seghezzo (2009), which considers sustainability as the conceptual framework within which the territorial, temporal, and personal aspects of development can be openly discussed. This idea can be represented with a new sustainability triangle formed by 'Place', 'Permanence', and 'Persons'. Place contains the three dimensions of space (x, y, and z), Permanence is the fourth dimension of time (t), and the Persons corner is the fifth, human dimension (i). The corners of the new sustainability triangle are closely inter-related and are difficult to deal with in a fragmented way as is generally the case for economic, environmental, and social issues. This conceptual framework, by assigning explicit relevance to spatial, temporal, and personal aspects is arguably especially appropriate to deal with the 'spatial and temporal heterogeneities that are paramount in the occurrence and understanding of water scarcity' (Molle & Mollinga 2003: 536) and with the fact that 'deprivation of water is unmistakably associated with poverty and is often seen as an offense to human rights and dignity' (Molle & Mollinga 2003: 529).

The Water and Sanitation Sustainability Index (WASSI) for Salta

Policy makers can only pay attention to things that are measured. Failure to identify and measure fundamental aspects of the sustainability of a management system will render these aspects essentially invisible. We developed a 'Water and Sanitation Sustainability Index' (WASSI) in an attempt to put numbers to the sustainability (or lack thereof) of a specific system. The WASSI can provide policy makers with a tool to understand the management system, identify weak points, and devise improvement and optimization strategies. Evocatively, WASSI sounds like 'huasi', a Quechua word meaning 'home'.

Sub-indices and descriptors

As required by the conceptual framework adopted, the index was divided into three sub-indices: Place, Permanence, and Persons. Each sub-index contains three 'descriptors' (Torquebiau 1992) or 'orientors' (Bossel 1999) (Table 1).

The 'Place' sub-index evaluates the relationship of the management system with its environment. This sub-index can be seen as a proxy to assess the system's interaction with the biophysical and cultural territory upon which it operates. Descriptors within this sub-index point to fundamental territorial aspects of the WSMS. Descriptor Availability reflects the actual existence of sufficient, clean water for human consumption. This is a quintessentially spatial and biophysical feature indispensable to build any management system. Availability is related to present water quantity and quality, but also to the perspectives of satisfying local water needs in the medium and long term. Descriptor Infrastructure is key to understanding current service quality, predicting future bottlenecks, and identifying investment areas. Adequate, up-to-date, and well maintained infrastructures, together with concrete technical and managerial tools are indispensable to correctly operate water systems and ensure the provision of safe drinking water for the population. Access to a sufficient, safe, and

Table 1 | Sub-indices and descriptors used to build the Water and Sanitation Sustainability Index (WASSI) for the city of Salta, Argentina

Sub-index	Code	Descriptor	Short definition
Place (territorial aspects)	A	Availability	Quantity and quality of the water available for human consumption and future availability based on current trends
	B	Infrastructure	Assessment of the water and sanitation infrastructure, including risks on human health and well being
	C	Coverage	Spatial distribution of water and sanitation provision systems
Permanence (temporal aspects)	D	Access	Compliance of the right to water including physical, economic and social availability
	E	Planning	Management capacity and institutional framework at the local level
	F	Participation	Opportunities and instances of public engagement with the water management authorities
Persons (personal aspects)	G	Use	Amount and patterns of water use in the area under assessment
	H	Impact	Environmental impacts produced by system deficiencies and personal behavior
	I	Satisfaction	People's feelings and perceptions about the quality and fairness of the water management system

affordable amount of clean water constitutes a specific human right enshrined in international legislation since the United Nations General Assembly declaration of 26th July 2010. Descriptor Coverage points to the fact that the geographical distribution of water sources and infrastructure is an important factor for the effective compliance of this right in a given area. It affects the management system in terms of costs of collection and distribution, and sometimes determines widespread accessibility. In fact, correlations have been found between the quality of water services and population distribution patterns (Renfrew 2009). It could be argued that failure to provide water and sanitation to informal settlements and marginal areas must be considered a failure of the entire WSMS, irrespective of legal aspects or corporate responsibilities.

Sub-index 'Permanence' intends to shed some light on the short, medium, and long-term aspects of the WSMS. This sub-index and its descriptors reflect local capacity to solve problems and improve the system. Descriptor Access is based on the premise that fair water and sanitation services must ensure that 'the three basic principles of quality, quantity and accessibility' are adequately met to cover the most basic human needs (Gleick 1996; Cahill 2005). Present access is directly linked to policies of the past. Therefore, this descriptor can be considered as a most physical evidence of former planning processes. Descriptor Planning assesses institutional aspects. The existence of an adequate institutional framework is necessary for the management system to continue to exist in the future. Institutions respond to cultural imperatives, are rooted in local history, and determine present and future management characteristics. The existence and effectiveness of institutions was considered as the central component of the temporal aspects of the system. Descriptor Participation, in turn, covers aspects essentially related to water governance and reflects the existence and efficiency of meeting and interaction points. This is essentially a description of the link between individual persons and the planning process.

Finally, the 'Persons' sub-index puts additional emphasis on the more personal aspects of the management system. The human dimension seems increasingly relevant in the case of water management in times of scarcity and unequal access to water and sanitation services. Descriptors within this sub-index intend to ascertain to what extent different sectors of society are effectively granted the right to water and the possible consequences this exercise might entail on the environment and their personal lives. Descriptor Use assesses in quantitative terms the effective, personal exercise of the right to water, and correlates to a responsible water use pattern. Therefore, consumption is compared with an acceptable threshold in order to assess its sustainability. Descriptor Impact is based on indicators of water pollution, which is a direct or indirect, sometimes delayed consequence of personal consumption patterns and cultural habits. Pollution may affect the quality of available water and, by significantly raising potabilization or drilling costs, its ultimate availability. Improvements in point-of-use water quality have been considered as the most important factor for the prevention of some water-related diseases (Waddington & Snilstveit 2009). According to UNICEF & WHO (2009), unsanitary environments, lack of improved sanitation facilities, and limited or no access to safe drinking water allow diarrhea-causing pathogens to spread more easily, causing an estimated 1.5 million under-five deaths every year. Descriptor Satisfaction is a general depiction of the most personal aspects of the system. Access to water and sanitation services effectively addresses the satisfaction of basic needs. It is logical to expect that the quality of the service would affect the personal satisfaction of customers and end users. This satisfaction could be measured with opinion polls or, indirectly, through statistics of service-related complaints from end users.

Indicators and variables

One or more indicators per descriptor were defined and estimated using a combination of adapted methods (Bossel 1999; Bertrand-Krajewski *et al.* 2000; Valentin & Spangenberg 2000; Hellström *et al.* 2004; Chaves & Alipaz 2007; Hajkowicz & Collins 2007; Hák *et al.* 2007; Bell & Morse 2008). Indicators were quantified through the measurement of one or more variables. When more than one variable or indicator was needed, we preferably selected three in order to strictly follow the conceptual framework. Brief descriptions of the indicators and variables used to build the index are provided in Table 2 and Table 3. Indicators and variables were selected in terms of their relevance to assess the satisfaction of the descriptors. The final decision regarding which indicators or variables to use was based on three basic criteria: (a) maximum possible coherence with the conceptual framework, this is the spatial, temporal, or personal aspects of the WSMS; (b) minimum potential correlation between parameters at the same level (overlapping is minimized if the conceptual framework is correctly applied); and (c) availability and reliability of local information. When more than one parameter qualified to those ends at a certain level, two approaches were followed to make the final decision: (1) we considered the possibility of aggregating parameters in a single value; or (2) only one parameter was selected after internal discussions within the research group.

Figure 2 shows a conceptual scheme of the entire WASSI represented as a hanging 'mobile toy', each parameter being calculated with and depending on the parameters of the lower level. The vertices of any triangle at any level need to be equally important in order to preserve the equilibrium of the entire structure. This is in line with the conceptual model that assigns similar importance

Table 2 | Indicators of the WASSI

Code	Indicator	Definition
A1	Water quantity	Average amount of water available per person in the influence area of the water system
A2	Trends	Expected trends in water quantity or quality
A3	Water quality	Water quality in the area assessed through physical, chemical or microbiological parameters
B1	Risks	Expert assessment of present conditions and safety of water and sanitation infrastructure
B2	Lifetime	Estimation of the residual lifetime of local water and sanitation infrastructure
B3	Diseases	Potential harmful effects on human health caused by deficient infrastructure
C1	Equity	Comparison of different areas in terms of access to drinking water or sanitation services
D1	Costs	Economic accessibility to water and sanitation services
D2	Information	Quantity and quality of free access information concerning the water and sanitation system
D3	Rights	Indicates whether everybody has access to the amount of water to cover basic water needs
E1	Institutions	Comprehensive assessment of the institutional capacity in the water sector
F1	Interaction	Number of functioning interaction points and participation instances
G1	Consumption	Water consumption in the area
H1	Pollution	Environmental pollution caused by the water and sanitation system
I1	Perception	Public perception of the technical quality of water and sanitation services

Table 3 | Variables of the WASSI. Each variable corresponds with one indicator in Table 2

Code	Variable	Definition
A11	Water production	Water produced in the area from surface, sub-surface and groundwater sources
A21	Wells depth	Yearly increase in the depth of water wells probably as a consequence of resource depletion or pollution
A31	Residual chlorine	Number of water samples exceeded in the value of residual chlorine during last year
B11	Water safety	A weighed average of the overall potential impacts of the risks associated to the entire water provision system
B21	Infrastructure age	Average age of water and sanitation infrastructure compared to ordinary lifetime figures
B31	Water related diseases	Occurrence of diarrheas in children under five years of age in critical areas of the city
C11	Lack of services	Population in critical areas without water and sanitation services compared to a control area
D11	Relative water cost	Proportion of the minimum wage necessary to pay water services
D21	Web sites	Assessment of the quantity and quality of the information contained in institutional websites
D31	Basic water allowance	Amount of water supplied for free by the water company
E11	Institutional assessment	Assessment of the institutional capacity in the water company in terms of funds, planning, and personnel
F11	Participation events	Number of significant participation events per year
G11	Excess consumption	Relative per capita water consumption above a given target value
H11	Untreated sewage	Untreated sewage discharged into the environment as a per capita proportion of water consumption
I11	Complaints	Monthly number of service-related complaints

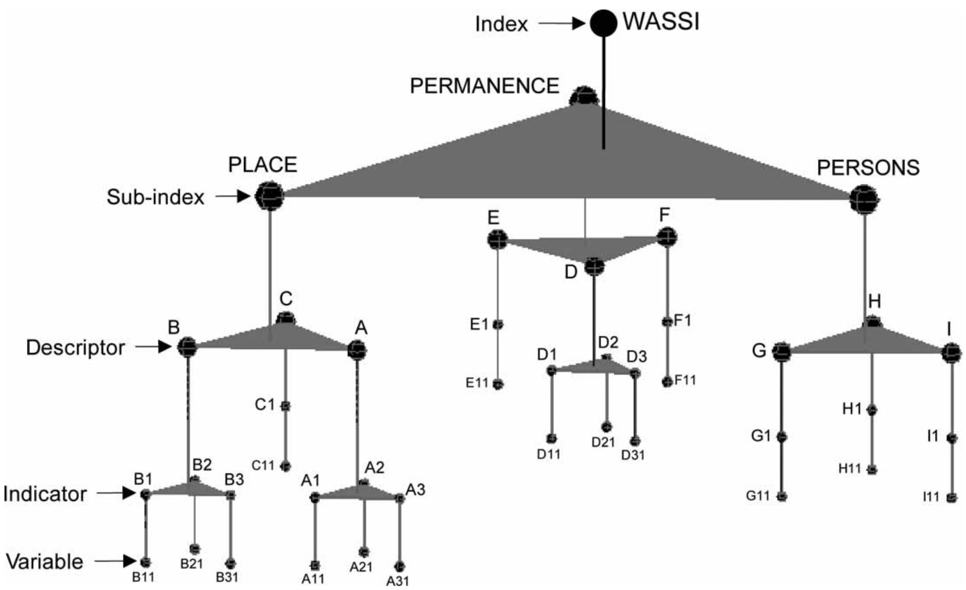

Figure 2 | Schematic representation of the Water and Sanitation Sustainability Index (WASSI) as a hanging mobile toy. See parameter codes in Table 1, Table 2, and Table 3.

to each corner and validates the absence of weighing in the calculation procedure. Some parameters are calculated with three parameters from the lower levels (i.e. sub-indices calculated with three descriptors) while other parameters are explained by only one parameter from the lower level (i.e. indicators calculated with one variable). We believe that, as long as the conceptual framework is respected, different configurations are possible depending on the local setting and the availability of reliable information. Parameters at all levels have been selected to be as comprehensive as possible, meaning that each variable, indicator, descriptor or sub-index can eventually be considered as a relatively self-contained, independent, sustainability meter. Parameters, especially those at the base of the hierarchy such as variables and indicators, can change from place to place and they can also vary over time for the same location, as long as the integrity of the conceptual framework is respected. This unique characteristic renders the WASSI extremely flexible and adaptable to different situations, whilst preserving its theoretical robustness. This is not a weakness of the method, as it might appear at first glance, instead the flexibility of the calculation process and the dynamic character of the index are arguably among its strengths.

Critical places

Water service levels in Latin America can be very different between countries. Diversity can also be found within countries, provinces, or even single cities. For that reason, we started our investigation by zoning the study area in order to preliminarily distinguish spatial differences in the quality or equity of water and sanitation services. Some indicators in the WASSI were calculated as comparisons between 'critical' and 'non-critical' places detected during the zoning stage. A critical place is defined as an area of the city that is deficient or vulnerable in one or more aspects related to water and sanitation. The zoning procedure and the identification of critical and non-critical places were based on a number of vulnerability criteria. Using different sources of information (field trips, interviews, and data from different institutions) vulnerability criteria were measured or estimated for the entire city and organized in a Geographic Information System (GIS) (McKinney & Cai 2002). The idea behind this procedure was that a map with these criteria combined could provide an immediate idea of the situation in different areas of the city in terms of their potential water and sanitation vulnerability. The identification of critical places is a simple, straightforward, and cost-effective approach to spot problems and inequalities in the WSWS. It provides a valuable starting point for the assessment of the sustainability of the entire system. This approach is based on the idea that sustainability is a direction rather than an end point. Therefore, sustainability assessment needs to focus on deficits and injustices rather than on achievements in order to be proactive and useful for decision making. Criteria chosen at the zoning stage must be simple and straightforward. Information must be readily available in order to minimize the time invested on such a preliminary analysis. Criteria can also be based on the local notion of sustainability and might be later useful to build variables or indicators during the actual sustainability assessment (as was the case for variables Water related diseases, Lack of services, and Complaints).

In this work, the selection of critical places was performed in terms of the following vulnerability criteria: (a) spatial coverage of water and sanitation services; (b) concentration of nitrates (mg/L) in groundwater; (c) the number of complaints received by the water company on water and sanitation services for different areas of the city; and (d) the index of 'Unsatisfied Basic Needs', locally known as NBI (Spanish acronym for 'Necesidades Básicas Insatisfechas'). The first criterion gives an idea of the spatial distribution of water and sanitation services and was seen as a rapid indicator of spatial aspects. To build the map we selected the worst-performing of the two services, represented in our case by the sewerage network. The second criterion points to urban pollution problems measured through an indicator of groundwater quality. Nitrates slowly migrate through the soil and can be considered as an indicator of the history of the water system and as an indirect proxy for temporal aspects. The third criterion is a sign of the quality of the service as seen by the end users and consumers; it therefore directly or indirectly represents personal aspects. The fourth criterion is a background index that takes into account, among other things, the availability of improved sanitation facilities within the household. It combines several indicators covering a broad range of poverty-related issues. The accuracy and efficacy of the NBI has been questioned but is still widely used as a direct indicator of poverty (Feres & Mancero 2001). NBI data were obtained from the Provincial Office of Statistics (Dirección General de Estadísticas 2010). This criterion can also be considered as an indication of the level of medium- and long-term planning, investment and maintenance provided by water companies. The availability of information was used as an additional general criterion to make the final choice of critical places.

Critical places have been selected among consolidated neighborhoods, defined as those with public health facilities (health centers or hospitals), an electricity grid, some kind of water and sanitation services, and garbage collection. Informal or recent settlements have been excluded to avoid extreme values that could bias the assessment. Based on the first zoning of the study area (Figure 3), a number of visits were performed to places with extreme values (both positive and negative) in order to validate the analysis and obtain a more extensive idea of the situation on the field. The identification of critical areas through the information and insight obtained with maps and field visits had a direct and indirect influence on the choice and calculation of sustainability indicators.

On one hand, the detection of problems and deficiencies in some areas of the city was useful to identify locally relevant descriptors, indicators and variables that were later used to build the entire index. On the other hand, while

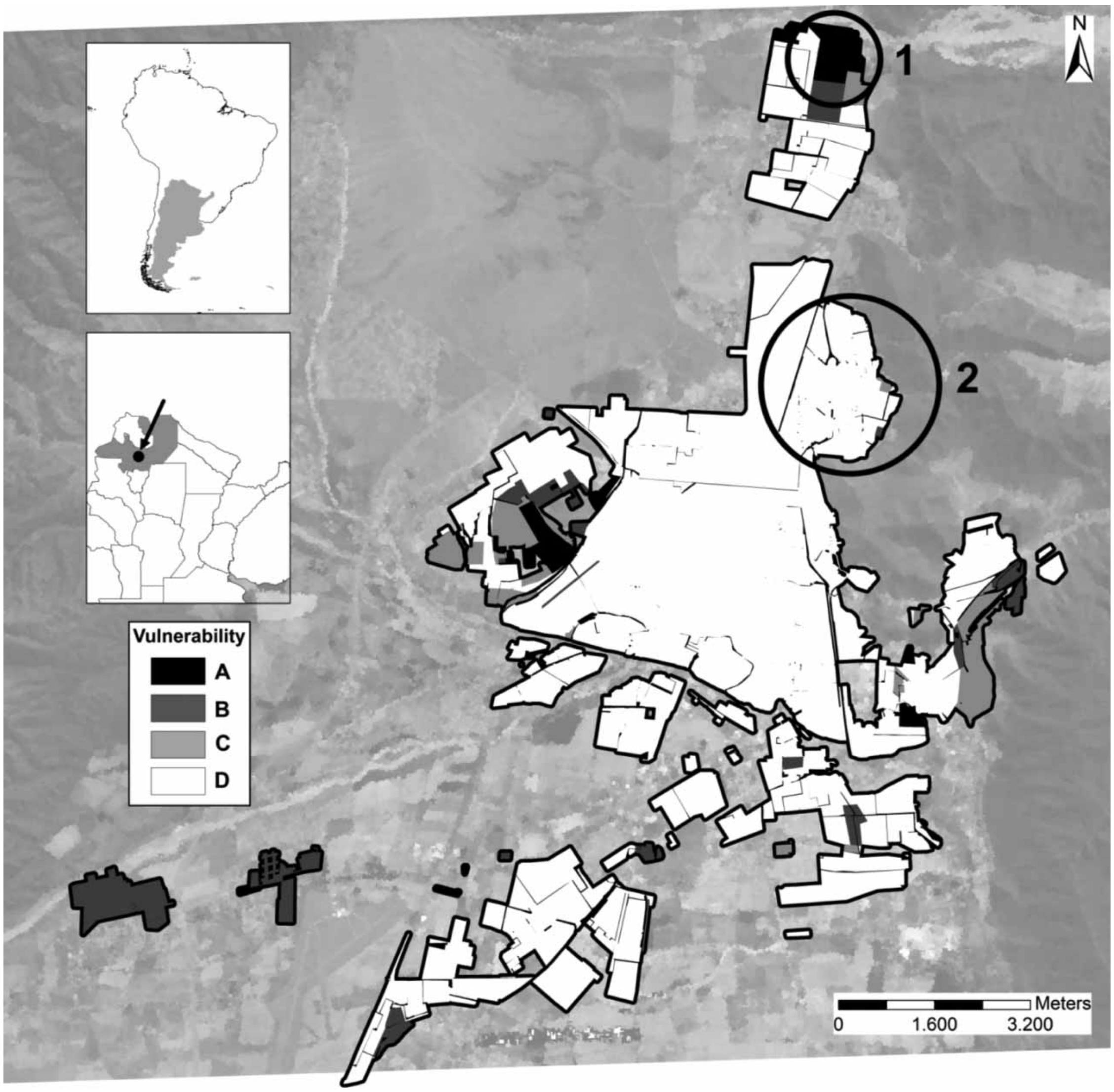

Figure 3 | Zoning of the City of Salta, Argentina, showing variations in terms of a spatial combination of the following criteria: (a) coverage of water and sanitation services; (b) concentration of nitrates in groundwater; (c) service-related complaints; and (d) unsatisfied basic needs. Vulnerability is graphically depicted in a gray scale where A is the most vulnerable (critical) and D is the least vulnerable (non-critical). Circles 1 and 2 indicate the critical and non-critical neighborhoods selected to calculate some sustainability indicators ('17 de Octubre' and 'Tres Cerritos', respectively).

most parameters were calculated as averages for the entire city, some were estimated only for critical places or as differences between critical and non-critical places. In the latter cases, such values were applied to the whole city, assuming that the sustainability of a system is highly dependent on the sustainability of its weakest component (Vishnudas et al. 2008). The process of selection of critical places is also place- and time-dependent and has to be adapted to local circumstances (Howard & Bartram 2005). Therefore, critical areas must be defined for each particular case. In this paper, the critical place selected was a northern quarter of the city called '17 de Octubre', a population of almost 4,000, located close to a sewage treatment facility (Government of Salta and Municipality of Salta 2009) (see Figure 3, circle 1). The non-critical place used as control was a relatively affluent neighborhood called 'Tres Cerritos' (see Figure 3, circle 2).

Data collection and analysis

Information was collected by several means including literature and press reviews, semi-structured interviews, field visits, and risk assessments. Semi-structured interviews were held with senior and technical staff with the provincial water company (CoSAySa – Compañía Salteña de Agua y Saneamiento S.A.), the governmental control agency (ENRESP – Ente Regulador de los Servicios Públicos), and the provincial Secretary of Water Resources (SRH – Secretaría de Recursos Hídricos). Interviews were useful to preliminarily identify critical places and to obtain a better picture of the WSMS from the point of view of those operating and controlling it. The description of the system and the construction of detailed flow diagrams for all processes, subprocesses and specific components were based on previously existing company information, interviews with technical staff, and site inspections. Field visits were performed to different areas of the city all along the research, and they were not restricted to the phase of selection of critical places and description of the system. During the visits it was possible to corroborate data obtained from other sources and provide context information to complement the use of indicators and variables.

Some indicators used for the sustainability assessment were obtained from a Water Safety Plan (WSP) elaborated for the water company by members of the research team. The WSP was based on the methodology proposed by the World Health Organization (WHO) (Bartram et al. 2009). The WSP approach is based on the principles of Hazard Analysis and Critical Control Points (HACCP) used in the food manufacturing industry and adapted to water supply. As stated by the WHO, a WSP is '… the most effective means of consistently ensuring the safety of a drinking-water supply … from catchment to consumer' (Bartram et al. 2009: 1). Hazards and hazardous events were preliminarily identified during visits and interviews. After that, the overall risk assessment was performed in a participatory workshop using a variation of the Delphi methodology (Linstone & Turoff 1975). Representatives of all the areas of the water company directly related to operation, maintenance or control of the water provision system were present during the workshop. Results were assessed by the study team and later discussed with the participants' feedback. Information was analyzed using the Simple Multiple Attribute Ranking Technique (SMART), a method based on the Analytical Hierarchy Process (AHP) (Saaty 2008). The establishment of a WSP was considered important as a baseline appraisal of the WSMS and a good starting point for a sustainability assessment under the assumption that unsafe water systems can hardly be sustainable. A number of modifications were introduced to the standard WSP methodology in order to adapt it to local circumstances and make it more useful to contribute to a sustainability assessment. A detailed description of these modifications is outside the scope of this paper.

Sustainability scale

The WASSI is a relative, but also a 'relatively absolute' account of sustainability. Quantitative and qualitative values assigned to the different categories were converted into a sustainability scale modified from Bossel (1999), as follows: $\text{Value} < 25 = \text{unacceptable}$ (red), $25 \leq \text{Value} < 50 =$ danger (yellow), $50 \leq \text{Value} < 75 = \text{good}$ (green), $\text{Value} \geq 75 = \text{excellent}$ (blue). The original scale ranked from 0 to 4. We believe that a centesimal scale allows a more intuitive and fast interpretation of results. The extremes of the scale (0 and 100) were linked to particular values of the categories under assessment. Linear relationships were assumed whenever possible to calculate the sustainability of actual field data. The reference condition or 'band of equilibrium' (Bell & Morse 2008) was set at a threshold of 50. Some measures and actions should always be recommended, irrespective of the sustainability value obtained by a system: (a) immediate relief and restorative measures in the lowest quarter; (b) corrective action in the second quarter; (c) optimization and transition procedures in the quarter above the band of equilibrium; and (d) monitoring and maintenance of the system in the top quarter.

RESULTS AND DISCUSSION

The whole WASSI for Salta is presented in Table 4. The overall value obtained for the index was 41.1 (see Table 4, bottom of column 13). This value is below the acceptability threshold of 50 and falls in the Danger category, meaning that correction measures must be recommended.

Persons is the worst performing sub-index of the WASSI, barely above the Unacceptable range (sustainability value: 28.9, see Table 4, column 13). Descriptor Impact within this sub-index obtained a very low value of 13.7 (see column 11 in Table 4) due to the fact that almost half of the domestic wastewater produced in the city ends up in the environment without appropriate treatment. Sub-index Permanence ranked close to the acceptability threshold, especially because indicator Institutional assessment obtained a good score of 62.7 (Table 4, column 9). Sub-index Place was also in the Danger zone in spite of the fact that the amount of good-quality surface and groundwater available in the area is excellent (indicator Water quantity received a sustainability value of 100, see column 10). However, systematic detection of drinking water samples without residual chlorine and a gradual depletion of groundwater sources reduced the value of descriptor Availability to 59.0 (column 11). Moreover, unequal distribution of water and sanitation services gave variable Lack of services a very low score of 18.8 (column 9).

As shown in Table 4, descriptors Coverage, Participation, Impact, and Satisfaction fell in the Unacceptable range. On the other hand, descriptors Availability, Infrastructure, Access, and Planning were in the Good range. The relatively low value of descriptor Use (sustainability: 48.7, column 11) is due to excessive *per capita* water consumption, which is above international standards. Based on data provided by the company and our own estimations, domestic water consumption ranges between 300 and 600 L/p.d, with an average most likely exceeding 500 L/p.d. Wastage during use and leakages from outdated water piping are probably responsible of much of this value.

A thorough analysis of the entire index gives an idea of the areas where improvements are most needed. The WASSI shows that water is abundant in the area in spite of some indication of groundwater depletion. Water consumption is above international standards, and it could be argued that a water saving program might greatly extend the capacity of current superficial, sub-superficial and groundwater sources. Judging by the results obtained, we see that both the institutional framework and available infrastructure seem appropriate. Still, the management system fails to provide widespread and sufficient coverage of water and sanitation services to the entire city. It could then be said that water problems in Salta are not related to its quantity but to the unequal way in which it is distributed and managed. The personal aspects of water management are severely overlooked. This is apparent in the lack of public participation in decision making instances and the numerous service-related complaints received by the water company.

Detailed description of all calculation processes and discussion on the rationale behind the selection of each transform function is not possible in this paper. However, it is important to point out that the lower and upper points of the transform functions (Table 4, columns 7 and 8, respectively) were selected based on a literature review and during workshops held within the research group. These values can (and must) be adapted to each setting and they can also change over time.

Figure 4 shows the WASSI and its sub-indices in modified radar diagrams. These diagrams, also called spider web diagrams or AMOEBA graphs, were first used for the description and assessment of ecosystems by Ten Brink et al. (1991). They can be a visual aid to understanding the complex issues of sustainability (Bell & Morse 2008). Shaded triangles can be understood as sustainability areas. The inclusion of the threshold value (as a thick line) immediately defines areas in which sustainability is below the

Table 4 | The WASSI for the city of Salta, Argentina. L_{dw}: Liters of drinking water; L_{ww}: Liters of wastewater

1	2	3	4	5	6	7 Transform function	8	9 Sustainability	10	11	12	13	14
Sub-index	**Descriptor**	**Indicator**	**Variable**	**Units**	**Value**	**0**	**100**	**Variable**	**Indicator**	**Descriptor**	**Category**	**Sub-index**	**Category**
Place	Availability	Water quantity	Water production	L_{dw}/p.d	537.9	50	250	100.0	100.0	59.0	Good	44.5	Danger
		Trends	Wells depth	m/y	1.04	2	0	48.1	48.1				
		Water quality	Residual chlorine	%	3.84	5	1	29.0	29.0				
	Infrastructure	Risks	Water safety	%	30.7	100	0	69.3	69.3	55.6	Good		
		Lifetime	Infrastructure age	Years	28.8	50	20	70.8	70.8				
		Diseases	Water related diseases	–	0.27	0	1	26.5	26.5				
	Coverage	Equity	Lack of services	%	84.0	15	0	18.8	18.8	18.8	Unacceptable		
Permanence	Access	Costs	Relative water cost	%	1.90	5	0.2	64.5	64.5	67.1	Good	49.9	Danger
		Information	Web sites	–	36.7	0	100	36.7	36.7				
		Rights	Basic water allowance	L_{dw}/p.d	87.7	5	50	100.0	100.0				
	Planning	Institutions	Institutional assessment	–	2.51	0	4	62.7	62.7	62.7	Good		
	Participation	Interaction	Participation events	N°/year	0.20	0	1	20.0	20.0	20.0	Unacceptable		
Persons	Use	Consumption	Excess consumption	%	51.3	100	0	48.7	48.7	48.7	Danger	28.9	Danger
	Impact	Pollution	Untreated sewage	%	43.2	50	0	13.7	13.7	13.7	Unacceptable		
	Satisfaction	Perception	Complaints	N°/1,000 p	190	250	4	24.5	24.5	24.5	Unacceptable		
												41.1	Danger

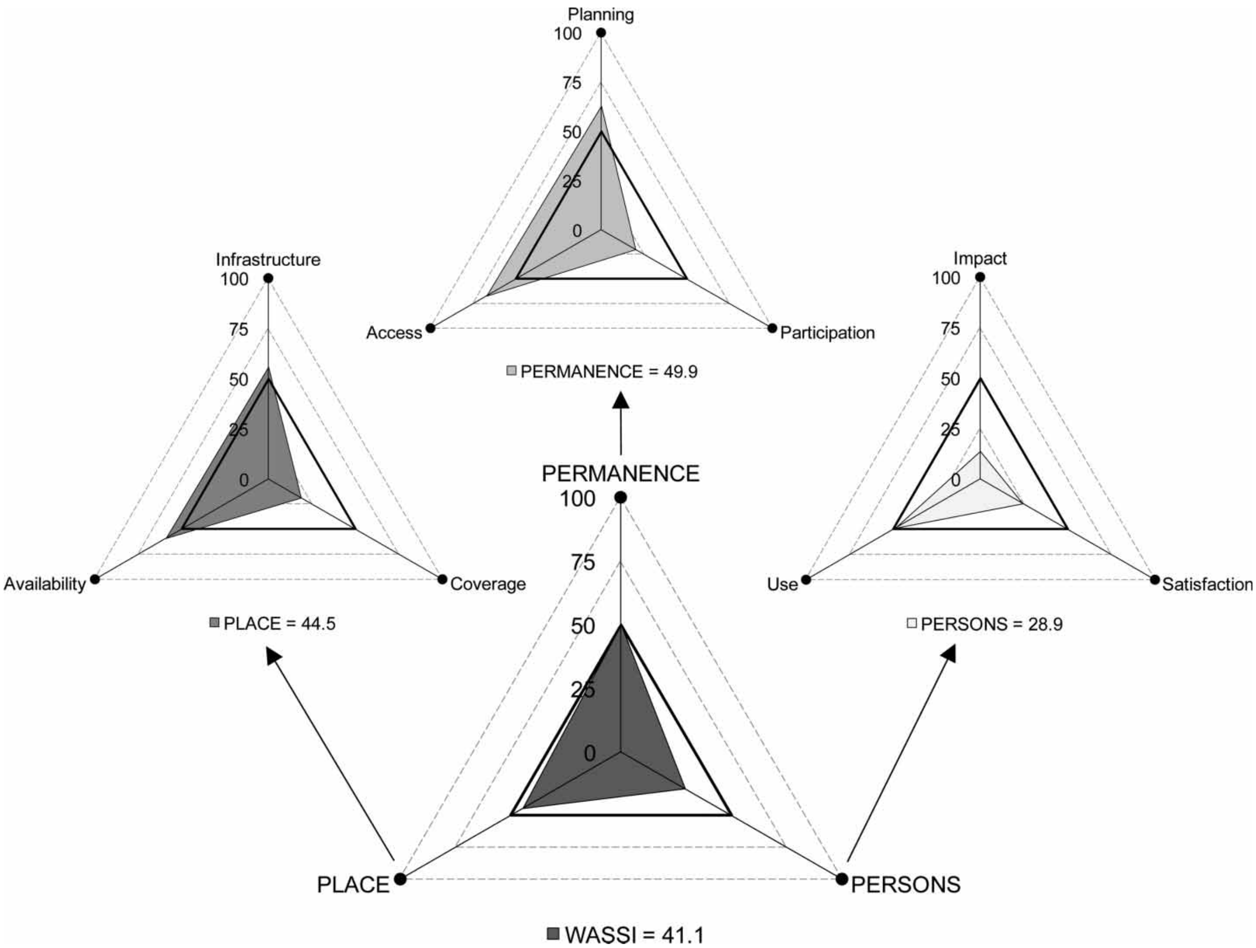

Figure 4 | The WASSI for Salta and its three sub-indices represented as a sustainability triangle (center). Details of sub-indices Place, Permanence, and Persons and their descriptors are shown as smaller sustainability triangles (on top, from left to right, respectively). The threshold value of 50 is indicated by full, thick lines. Shaded triangles represent 'sustainability areas' at each level of analysis.

threshold and improvements are needed. Similar graphs can be built for descriptors or indicators built with three parameters in order to visually detect non-compliances, facilitate the transfer of results to relevant stakeholders, and disseminate the findings to a wider audience. Multi-level sustainability triangles are straightforward and easy to understand. Unlike most AMOEBA graphs found in literature, all categories shown together in a multi-level triangle belong, by definition, in the same group of related variables. In this way, the graphic depiction of any category gives an immediate idea of its 'sustainability' inasmuch as sub-categories always represent, to the maximum possible extent, the territorial, temporal, and personal aspects within this category. Even so, a depiction of all indicators together can also give an idea of the sustainability of the entire system (Figure 5).

Indices and indicators are a relatively easy way to represent a complex reality. Their comparative power and their ability to show trends and detect changes are generally recognized. They are a potent tool for communication and dissemination purposes and can also be a starting point for additional discussions on sustainability issues. Indicators necessarily simplify reality and the meaning of their absolute value may be contested. For that reason, the information provided by the WASSI must be complemented by a thorough and critical description of the context to put the assessment in perspective. This description should include, among other things, a brief account of some relevant aspects

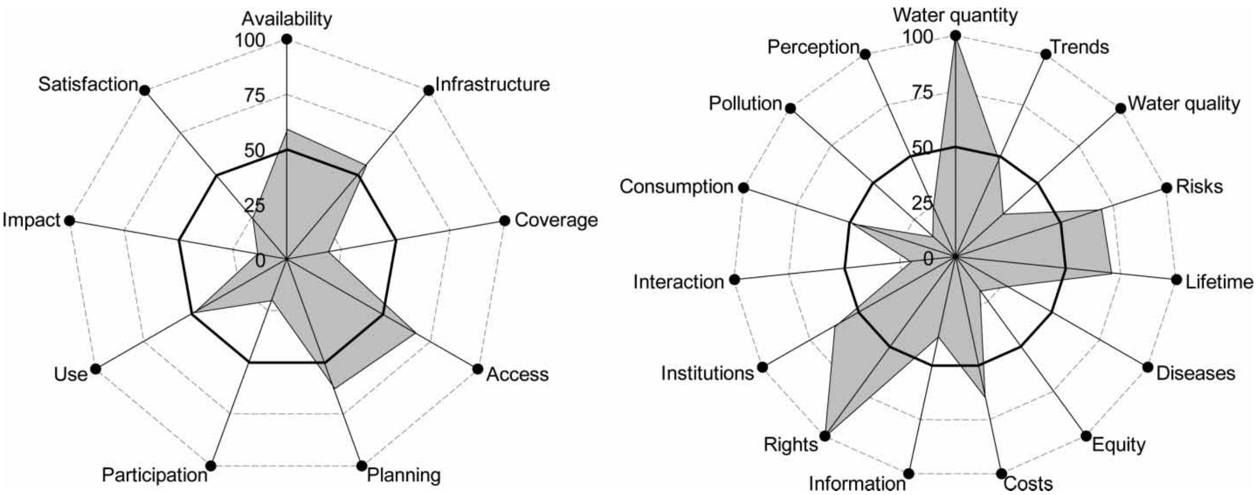

Figure 5 | Descriptors (left) and indicators (right) of the WASSI shown together in spider web diagrams or AMOEBA graphs.

of the local history and norms, a portrayal of power relationships among different actors, a short depiction of the political and economic environment, and other issues related to water governance, a key ingredient to ensure long-term quality services (Galaz 2007; Hufty 2007).

The index developed is both broad and specific. We believe that it has to be relatively broad to be coherent and conceptually robust. Our contention is the index is also specific enough to be useful and applicable in different cases, scales and circumstances because it has been built with down-to-earth indicators and variables which are context-related and problem-oriented. We also believe that measuring sustainability with solid tools based on theoretically sound definitions is the first indispensable step for the delineation of an action plan. The very measurement of sustainability, by indicating strengths and weaknesses of a given system, provides clear guidelines for change. The direction of the change suggested by such analysis is not random; on the contrary, it is by definition oriented towards a more sustainable system, whatever the local idea of sustainability might be. The method sketched in this paper can be then seen as both a practical assessment tool and a general theory of change. The end users of such an assessment, in the case of the WSWS in our case study, are local water providers and governmental control agencies. This is not to say that the results will immediately be adopted by these actors, as this depends on many other political and economic factors. A thorough political ecology analysis will help understand the intricacies of the sustainability of complex management systems and the political and economic implications of the specific measures that could be implemented to improve the system.

This is the first time the WASSI was calculated for Salta. For that reason, it is too early to identify sustainability trends and predict possible, probable, and desirable scenarios. The construction of such scenarios could be important to shed more light on the path to sustainability. Availability and reliability of information is a critical point in the assessment process, especially in so-called developing countries. The more information, the more accurate the index becomes. Yet the lack or inaccessibility of information is also an indication of the quality and transparency of the management system. For that reason, the index should be quantifiable even in cases where information is not readily available because policy makers make decisions anyway, with or without information. Lack of information may affect the calculation of some descriptors but it should not prevent the index from being calculated, given that the very objective of this calculation is to improve the quality of the management system, whatever the starting point might be.

A delicate balance must be struck between all possible options during the selection of assessment categories in order to respect the five-dimensional sustainability concept used as a conceptual basis. This balance is required to give equal priority to equally important aspects. The conceptual integrity of the method requires each corner of the different triangles be subdivided into three categories, with each subcategory representing the territorial, temporal, and personal aspects at that level. Exceptions and specific cases always exist, and more complex polygons could be useful in some cases. Sustainability issues are multi-faceted. The assessment of sustainability must acknowledge this complexity. Yet it has to be as simple as possible to be a useful tool for change. Selection of assessment categories according to a coherent conceptual framework and a tiered, multi-level analysis, ensure that, to the maximum possible extent, the partial and aggregate results truly assess the sustainability of the system for the specific context under study. In this way, coherence between theory and practice is fundamentally enhanced.

All descriptors are closely linked to one another and they are always interacting. Links could not only be found between different categories at the same level, but also between categories at different levels. We believe that by first differentiating and later integrating all descriptors in a single measure, a comprehensive idea of the sustainability of the system can be obtained. The weighting procedure, one of the most contested parts of any multi-criteria analysis, was not necessary in this study since, as discussed above, categories at each level of analysis have been directly related to equally fundamental elements of the local definition of sustainability. Assigning different weights to the corners of the triangles might therefore be objectionable. However, rigid adherence to any theoretical conceptual framework is not prudent. There could be situations in which weighing the relative importance of sub-indices, descriptors, indicators, or variables might be advisable. It is clear that a new sustainability assessment framework and methodology such as the WASSI might not be applicable in all cases. Some indicators may not be relevant to all systems and it is possible to imagine circumstances where more (or less) categories may better represent the sustainability of local management systems. Moreover, the results of the analysis are strongly affected by the quantity and quality of the data. Recognition of these problems, which arguably apply to any assessment method, is important to put the results in perspective. For that reason, the WASSI should be assessed and refined on a regular basis to acknowledge changes and modifications in the system and its components. Participation of relevant stakeholders and external experts in the assessment process is desirable. Such participation will help in the identification of potentially more pertinent indicators that will improve the index and its usefulness as a decision-making tool (Doelle & Sinclair 2006).

The selection of critical places and moments is a particularly contentious issue. Many descriptors of the WASSI are intended to identify differences between sectors of the area under study, as a proxy for inequality. The calculation of indicators within these descriptors requires that the worst and best place, in terms of the WSMS, be selected for the entire city. To be useful for decision making, this selection needs to be relatively fast, without engaging in a broad and long assessment. However, 'critical' and 'non-critical' places are subject to constant changes. If further studies determine that the places used for comparison were not respectively the worst and the best of the system, indicators need to be recalculated. Arguably, the value of the index can only decrease in these cases. Therefore, deficiencies detected by the index and the concomitant measures suggested can be seen as a minimum requirement to improve or optimize the management system. This also ensures that efforts and investments are not disproportionate. Besides, the threshold against which the index is compared is always, by definition, the minimum goal in terms of sustainability. Raising the threshold would immediately increase the amount of measures needed to enhance the sustainability of the management system.

Other measures of sustainability, such as the ecological footprint or the water footprint (Hoekstra 2009), could complement the findings of the WASSI. However, some of these aggregate indices might fail to consider aspects that could be essential to the local concept of sustainability (Pillarisetti & van den Bergh 2010) and might not point 'to what is important in the world' from a local perspective (Meadows 2000). On the other hand, the measurement of long lists of loosely connected indicators like those proposed by the United Nations (2007) requires a lot of basic information which is not always available. We believe that compliance with a coherent conceptual framework, careful adaptation of the assessment method to each single context, and a transparent, if possible participatory, transformation into sustainability units are needed to obtain a realistic and useful account of the sustainability of complex management systems.

CONCLUDING REMARKS

A water and sanitation sustainability index called WASSI was developed and calculated for the city of Salta, in northern Argentina. The value obtained for the entire system was 41.1 in a scale of 0–100. This value falls in the Danger range, below an acceptability threshold fixed at 50, and indicates that immediate measures need to be taken. All three subindices (Place, Permanence and Persons), fell in the Danger range, with some descriptors in the Unacceptable range (Coverage, Participation, Impact, and Satisfaction).

The WASSI was sensitive to detect variations between different aspects within the WSWS in Salta, even when confronted with uncertain or even ambiguous information. The index detected weaknesses and deficits that indicate areas where improvements are needed. The main steps for the construction of the WASSI were the selection of an adequate conceptual framework, and the identification and measurement of pertinent descriptors, indicators, and variables.

The measurement of a single sustainability score for an entire city is a very powerful way to disseminate the results to wider audiences and to convey unambiguous messages to policy makers. The simplicity and straightforwardness of a single score is complemented with the information contained in its nine descriptors and fifteen indicators, each one of them built with specific variables covering a wide range of relevant issues. Therefore, it can be argued that the WASSI is not only understandable but also sufficiently complex as to facilitate an integrated assessment and monitoring of the entire water and sanitation system of the city. We believe that this approach could be useful to assess WSMS in a conceptually coherent and practically efficient way. The fact that the WASSI was built with locally relevant sustainability indicators, makes it useful to identify courses of action and improvement strategies. For that reason, we are convinced that this index will be useful for service providers, control agencies, research teams, and grassroots organizations who are interested in assessing WSMS from a sustainability perspective.

The WASSI can (and must) be built with the amount and quality of information that is readily available, making it a suitable method to be applied in developed and developing countries alike. The methodology allows for the inclusion of relevant actors and stakeholders in the entire calculation process. Other methods from the natural and social sciences may be necessary to improve our understanding of the meaning, usefulness, and limitations of sustainability indicators. Overall, the WASSI holds a lot of potential as an effective tool for the optimization of WSMS towards sustainability.

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