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Review

Adaptive capacity indicators to assess sustainability of urban water systems – Current application

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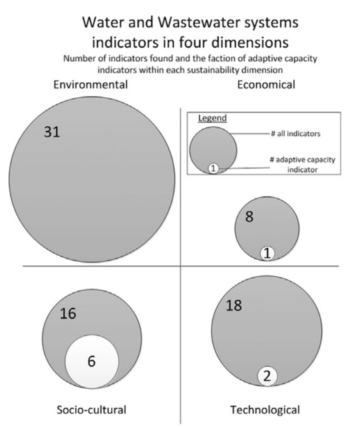
HIGHLIGHTS

- The ability of technological systems to be changed is essential to maintain sustainability.
- Indicators of adaptive capacity are underrepresented amongst sustainability indicators.
- Urban water studies are dominated by a view of stability, certainty and equilibrium.
- System control indicators could be more suitable to assess adaptive capacity.

GRAPHICAL ABSTRACT



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ABSTRACT

Sustainability is commonly assessed along environmental, societal, economic and technological dimensions. A crucial aspect of sustainability is that inter-generational equality must be ensured. This requires that sustainability is attained in the here and now as well as into the future. Therefore, what is perceived as 'sustainable' changes as a function of societal opinion and technological and scientific progress. A concept that describes the ability of systems to change is adaptive capacity. Literature suggests that the ability of systems to adapt is an integral part of sustainable development. This paper demonstrates that indicators measuring adaptive capacity are underrepresented in current urban water sustainability studies. Furthermore, it is discussed under which sustainability dimensions adaptive capacity indicators are lacking and why. Of the >90 indicators analysed, only nine are adaptive capacity indicators, of which six are socio-cultural, two technological, one economical and none environmental. This infrequent use of adaptive capacity indicators in sustainability assessments led to the conclusion that the challenge of dynamic and uncertain urban water systems is, with the exception of the socio-cultural dimension, not yet sufficiently reflected in the application of urban water sustainability indicators. This raises concerns about the progress towards urban water systems that can transform as a response variation and change. Therefore, research should focus on developing methods and indicators that can define, evaluate and quantify adaptive capacity under the economic, environmental and technical dimension of sustainability. Furthermore, it should be evaluated whether sustainability frameworks that focus on the control processes of urban water systems are more suitable for measuring adaptive capacity, than the assessments along environmental, economic, socio-cultural and technological dimensions.

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Contents

1. Introduction

Sustainable urban development has been identified as a key challenge of society. Sustainability in urban water and wastewater [hereafter referred to as urban water] management has received much attention by academic scholars. A Scopus search with the words 'sustainabl*' and 'urban water*' resulted in 2390 papers published since 1990 with a steep increase since the turn of the century (ref. date 13/09/2015 – details in online support material). The most widely used definition of sustainability is that of Brundtland et al. (1987) who define sustainable development as: "…a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Juwana et al. (2012) provide a review of a number of sustainability definitions applied to water systems. One definition that is widely used is that of Loucks (1997): "Sustainable water systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental and [engineering] integrity." These definitions indicate that sustainability should be attained for the social, economic and environmental systems. In addition, the definition of Loucks (1997) also points towards the role of technology and engineering in enabling sustainable development. Many scholars argue that innovations in urban water systems are required to address, amongst other things, global phosphorus depletion and energy neutrality of wastewater systems (Shannon et al., 2008; Verstraete and Vlaeminck, 2011). Finally, but most crucial for this paper, sustainability also requires intergenerational equality.

Inter-generational equity emphasises that sustainability relies on the continuous function of social, economic, environmental and technological systems. Sustainability therefore, must be maintained in the here and now as well as in the future. Hence, developments and changes that take place over time are key factors to be taken into account to maintain sustainability. For instance, as population grows from low density rural to high density urban, the strain on water resources will rise and tighter standards for wastewater treatment need to be met to ensure that the pollutant load does not exceed the carrying capacity of the receiving ecosystems. Similarly, what is considered 'sustainable' or 'unsustainable', will change with technological progress, societal opinion and regulation. This is evident in tighter environmental standards, 'best available technology' regulations and reduced societal acceptance of environmental damage. Precisely these, and other dynamics, were identified by Neumann et al. (2015) who examined the changes taking place in the wastewater system of Zürich over the last 140 years. They, and a number of other authors, therefore proposed that a sustainable urban water system is one that can cope with, and adapt to, changing circumstances (Brown et al., 2009; Daigger, 2012; Hering et al., 2013; Vairavamoorthy, 2009; Wilderer and Schreff, 2000). Similarly, Pahl-Wostl et al. (2007) call for more adaptive water management to make it operational under changing socio-economic boundary conditions and climate change. They argue that this type of management can be achieved by promoting institutions and networks that facilitate the collaboration between actors. From the perspective of engineering, Jeffrey et al. (1997) argue that: "if [water and wastewater] technologies are to make a genuine contribution to the achievement of sustainable communities and a sustainable world, then the pertinent focus of attention should be on the design, operation, and management of adaptive technologies and technological systems." In the same line of argument Spiller et al. (2015) present a review of technological options and a planning guideline for flexible[1] and adaptive urban water and wastewater systems.

To progress towards sustainability, indicators are a key tool for science, policy and water managers, because they are a means to summarise, focus and condense complex information to a meaningful and manageable amount (Lundin, 2003; Singh et al., 2009). As a result enabling communication about sustainability and to define strategies on how to progress towards sustainability (Singh et al., 2009). In this article, the focus is on the identification of indicators that measure the ability of the urban water systems to be altered and transformed (Milman and Short, 2008). Indicators that measure this property are termed 'adaptive capacity indicators'. The adaptive capacity of a system is essential to maintain resilience, where resilience is defined as (Walker and Meyers, 2004): "The capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structural identity and feedbacks".

Defined as such, resilience describes a system's ability to resist and withstand change – its coping capacity. However, it also includes the system's 'adaptive capacity' or the ability of the system to adapt to stress

[1] To avoid confusion between the terms adaptive and flexible, the term adaptive, adaptivity etc. will be used in this article. However, Spiller et al. (2015) suggests that flexibility is a more suitable term to describe the potential for technologies to be adapted, because flexibility implies that an external agent is required to implement change.