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Issues, Dimensions and Approaches of Assessing Urban Water Security in Developing and Emerging Countries: An Inclusive Perspective

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Abstract

Urban water security addresses various water challenges in a city including its urban and peri-urban area where the problems are not only depending on its physical water availability in a straightforward manner but also on its relations *to* and influences *by* social, cultural, economic and political factors. Hence, this chapter takes a review approach and aims to unravel the biophysical and socio-cultural relationships that shape the urban water security from an emerging country perspective, exploring the implications of including social and environmental changes and the possibilities in achieving urban water security. We will show that, although several concepts and approaches have emerged focusing on issues such as water-energy-climate nexus and urban water sustainability, most of these approaches fail to consider social perspectives and their relationship with bio-physical environment at a micro level. Existing urban water evaluation approaches are not holistic; often focusing more on bio-physical and technical factors (such as water supply and drainage systems within urban areas) rather than evaluating the entire socio-ecohydrological performance of the urban area. They currently do not account for the multiple functions of water as a resource across the urban landscape and do not consider the interwoven relations between water and socio, cultural, political and economic factors. This constrains our ability to measure what influence on water security, design interventions and manage urban areas in ways that may achieve overall water security. Whilst these approaches can show how components of urban areas' water systems are performing along the dimensions of water supply and drainage systems, a comprehensive framework is needed to frame the problems, monitor or inform progress that accounts for the wide range of factors and associated issues that impact overall water security. This will in term impact the chances of successfully and sustainably addressing issues of urban water insecurity. The chapter first discusses the various dimensions, measurement approaches and indicators used in similar research. In the second part, we propose a comprehensive framework for measuring and evaluating water security for the cities, particularly for emerging countries, in a holistic manner aiming to contribute positively to the future planning and management of sustainable urban water security.

Keywords: SDGs, dimensions, Gender, Inclusive approach, DPSIR

1. Introduction

Water security entails ensuring every citizen with the amount of quality water they need to safely live their everyday life (Narain, 2010). In urbanized areas, unrestricted population growth (Falkenmark and Widstrand, 1992; Ravell, 2014), poor governance (Bakker and Morinville, 2013; Biggs *et al*, 2013; Cook and Bakker, 2012) and mismanagement of the water supply system (Piesse, 2015) as well as social inequality (Blanca, 2016; Goff and Crow, 2014; Jepson *et al*, 2017) are among the factors that cause and

influence water insecurity. In addition, superordinate physical processes like effects of climate change accelerate the insecurity of water (Bar and Stang, 2016; Turrall et al, 2011). Overall, Urban water security (UWS) can be conceptualized as being the result of socio-economic activities in metropolitan, urban and sub-urban areas (Grey and Sadoff, 2007).

This chapter focuses on challenges of urban water insecurity in emerging countries. These countries frequently are subject to a dearth of financial potential to mitigate water related problems. Water security is one of the most concerning topics in these countries, and already disadvantaged parts of the population are disproportionately affected (Obani and Gupta, 2016; Pahl-Wostl et al, 2016). However, due to a range of constraints, including economic conditions and socio-political circumstances, accomplishing urban water security status is not given the priority it merits in most emerging countries (Pahl-Wostl et al, 2016).

Rapid and continuous changes dominated by the economic part of the development are forming new urban geographies in emerging countries. As a result, new geographies are created on top of old, colonial geographic areas for the production and consumption of the resources. These economic developments are leading to spatial and social inequalities and increase water insecurity as well as environmental problems such as pollution and waste management. The rising pressures and issues in water security signify that urban environmental problems are becoming critical to manage.

This chapter reviews different practices to evaluate the UWS as they relate to concepts of sustainability. We also review in what ways water insecurity is related to societal issues in emerging countries. Quantification of UWS is the heart of any water management approach. This chapter forms part of a growing body of quantitative approaches to analyze water security. Addressing the lack of research taking a holistic approach by including physical and social, economic and political factors, this chapter outlines an assessment framework of water insecurity in urban areas that considers *all* related disciplines and their interrelationships. A conceptual model is provided that encompasses the complexity of the interrelated issues associated with UWS. Incorporating socio-economic indicators in its proposed quantitative framework intends to achieve a holistic measurement model. The chapter starts out with a discussion on the UWS and the environmental sustainability issues of the cities in emerging countries. The next sections discuss the various dimensions, approaches and indicators used in similar studies. Finally, the chapter proposes a comprehensive framework for measuring and evaluating the status of UWS, particularly for emerging countries.

2. Issues of urban water security

There is no universally accepted definition of water security. All the current definitions make use of different approaches to measure water security based on different sets of goals, such as ‘water supply security’ (e.g. Lundqvist et al 2003, Padowski et al 2016, Grafton 2017), ‘urban water sustainability’ (Larsen et al, 2016) etc. (see appendix 1 for definitions of water security). Even though the definitions differ, there are a few common factors which are integrated in all of them, such as safeguarding clean and adequate water accessibility, minimizing water-related threats and implementing policies for governing the water as a vital resource. Adequacy of water and sanitation is the priority in an equity-based goal of human prosperity and financial improvement, to guarantee security against water-borne contamination and water-related catastrophes, and, maintaining ecosystem services (Brears, 2017).

Over the past decades definitions of water security have shifted from a focus on human livelihood and its involvement in the physical water management to its engagement with the ecosystem (appendix 1). Water security has become a main factor in social, political, public health, economic, environmental and other concerns — and acts as a central link between them (Lundqvist et al., 2003). In consequence, we find that a range of core issues is required to be addressed in order to achieve and maintain water security in different geographic scales and contexts. When it comes to research on water security in urban areas, the main issues considered in previous studies include:

- **Supply** of enough water for socio-economic development and other different activity areas like energy, transport, industry, tourism etc.;
- **Equal and impartial access** to safe and enough drinking water at affordable costs to meet basic needs including sanitation and hygiene, and to maintain health and levels of well-being;
- Protection of **human rights** for safe access to adequate water **for all**;
- Preservation and protection of **ecosystems** in water allocation and management to maintain their ability to deliver and sustain functioning of essential ecosystem services including cultural ecosystem services;
- Collection and **treatment of waste water** for safeguarding human life and the environment from pollution;
- Collaborative approaches within and between countries to promote sustainability and cooperation for **transboundary (intra or inter states) water resources management**;
- Uncertainties and **risk management** for water-related hazards, such as floods, droughts and waterborne diseases within a given time duration and
- Good **governance and accountability**, appropriate and effective legal regimes, transparent, participatory institutions, properly planned, operated and maintained infrastructural facilities; and capacity development.

As can be seen from the above researchers have approached water security from a range of angles, however we argue that as current pluralistic societies face many challenges studies analyzing water insecurities should reflect these pluralities by applying comprehensive approaches to research. Water security in today's urbanized areas is driven by various environmental, economic, political and social forces. They form a complex system of closely coupled processes and feedback effects that are not yet sufficiently understood. Knowledge of these interactions is essential since the water as a resource is the base for all human activities. While seeking to achieve water security at a global scale, specific attention is required to analyze the aggregated effect of water management decisions and the effects at micro level. This is crucial for decision makers to consider as they seek to achieve the Sustainable Development Goals (SDGs).

Water security is crucial to address in emerging countries. The highest number of people affected by water related risks in urban areas – such as scarcity of required quality water or exposure to meteorological hazards such as floods – are from emerging and developing countries (ADB, 2014; WHO, 2017). Moreover, almost 99% of the people lethally affected by water-related causes living in the developing world (WHO, 2008). Gaps between national and regional water policies and the absence of enough management plans are major causes for water insecurity in these countries. Issues include not having the necessary funding for the upkeep of water purification, distribution, and water extraction facilities, to reduce or mitigate the problems associated with waste water generation and related threats to downstream areas; approximately 1.1 billion people are affected by these issues (Watkins, 2006). Technical and managerial inefficiency in water-supply infrastructure which endangers quality issues related to water-environment sectors sculpts the symptoms of water insecurity in the urban areas of developing and emerging countries (Lundqvist et al., 2003; Mukherjee et al., 2018; Shaban and Sattar, 2011).

Securing water, for both society and environment, emphasizes the integrated management of water resources to maintain sustainable growth (Sarvajayakesavalu, 2015; Barbier and Burgess, 2017). SDGs elude to the multidimensionality and crucial importance of water security to achieve sustainable development and underlines the need for a holistic approach such as that presented here. SDG 6 calls

particularly for clean water and sanitation for all people, paying special attention to the needs of women and girls and those in vulnerable situations (Goal 6.2) by supporting and strengthening the participation of local communities for improving water and sanitation management (Goal 6B). Other SDGs also include different water and sanitation targets, such as

- end of malaria and other waterborne diseases (Goal 3.3),
- reduction in number of deaths from water and other pollution and contamination related risks (Goals 3.9 & 6.3),
- proper management of water related disasters (Goal 11.5) and
- chemical wastes to minimize the hazardous impacts on water (Goal 12.4)
- with the focus on protecting the poor and people in vulnerable situations (Goal 11.5) and
- conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services including wetlands (Goals 6.4, 15.1).

Particularly focusing on urban areas, SDG 11 aims at ensuring the development of sustainable cities and communities by focusing on ensuring access to safe and affordable housing, upgrading slum settlements, investing in public transport, creating green public spaces, and improving urban planning and management in a way that is both participatory and inclusive. Heading for "urban water security" faces complex relations inside and amongst the human and water relationship in urban areas, including a high spatio-temporal variability. This cooperation changes regionally in time and space including physical characters as well as urban development, demography, socio-economy and administration and might be affected from past urban developments (Brears, 2017). Thus, UWS is nothing but a „*persistent condition in a limited urban region under which water ecosystems can ensure the adequate access, safety, and affordability of water to meet minimum livelihood standards and human feelings of psychological security*“ (Huang *et al*, 2015, p. 3903).

3. Dimensions for quantitative assessment of urban water security

For the concept of water security there is no established or widely approved set of dimensions for assessment. Accordingly, here we set out to establish a comprehensive framework to study this complex issue. An urban area is defined as a socio-ecological system interacting between different socio-environmental dimensions (Romero-Lankao and Gnatz, 2016). In the literature, assessment dimensions of urban water systems include environment, society, culture, economy, politics, technology and governance (Romero-Lankao and Gnatz, 2016; Cunha Marques *et al*, 2015). However, scholars have differed in how they measure and which dimensions they include to assess the sustainability of urban water systems. The Global Water Partnership (GWP) (2012), separates socio-economic dimension into social and economic categories for all scales. Gray and Sadoff (2007) propose to use health, livelihood, ecosystem and production (Pahl-Wostl and Knüppe, 2016) and Shaban and Sattar (2011) argue that infrastructure for water supply and waste water management also should play a vital dimensional role. In addition, management of risks emanating from climate change issues are also mentioned as an important dimension to consider (Shaban and Sattar, 2011). Therefore, in order to integrate socio-cultural-economic-political issues in UWS assessment, the following challenges are amongst the most urgent issues identified to date

- 1) Secured access to enough and quality water to cover basic human needs for all despite of socio-economic, political and cultural odds,
- 2) Technological as well as governance efficiency, and

3) Systems transformation to provide sustainable water services.

In the following we will discuss different dimensions related to **a)** availability of water, **b)** risks associated with water, **c)** issues related to water management in the developing countries, **d)** the dynamic relationship between the bio-physical environment and society as well as accessibility issues related to **e)** gender dimension, **f)** culture and **g)** politics. These all are needed to be considered at the end to achieve a comprehensive and holistic analysis of UWS.

a) The availability of fresh water

As cities grow and their populations increase, so does demand for water. A recent report from the World Bank (2017) points out that around 50 percent increase in urban water demands is anticipated within the next 30 years. By 2025, annual demand for municipal water in the world's large cities is expected to have increased by nearly 80 billion cubic meters, from around 190 billion cubic meters per year in 2012 to about 270 billion cubic meter per year in 2025 (Bergkamp et al, 2015). Many cities, regions, and countries around the world are faced with a trifecta of pressures: rapid urban population growth, economic expansion, and competing demands. These forces of change are tightening the availability of water resources in areas where tackling water scarcity is already a critical challenge (World Bank, 2017). The mission of securing and planning a sustainable water supply for urban areas in water scarce regions, particularly developing and emerging countries, is clearly no easy feat. Particularly for developing and emerging countries, water scarce cities are facing these challenges every day. Regions as diverse as the Middle East and North Africa, South and Central Asia, and parts of Latin America are still trying to explore new approaches for a water-secured future. Another aspect of water supply is leakage in the distribution system. Leakage-loss- rates of 50% are not uncommon in urban distribution systems. Around 250 to 500 million m³ of drinking water gets lost in many large and mega cities each year. Saving this amount could provide an additional 10 to 20 million people with drinking water sole in the mega cities (UN Water, 2015). With the concentration of large numbers of people and economic activities to relatively small geographical areas, augmentation of supply of water, i.e., availability of freshwater, for the cities is the first dimension to be considered for any assessment approach (Lundqvist et. al., 2003).

b) The importance of risk

Water related risk has been mentioned as a crucial dimension by a range of authors. According to UN Water (2015), in 2014 828 million people lived in slum conditions, lacking basic services and this number grows by 6 million each year. Many slum dwellers die each year as a result of inadequate drinking water and sanitation services. Many slums are built in flood-prone areas and the areas and people in them are particularly vulnerable and at risk (UN Water, 2015). Cook and Bakker (2012) identified vulnerability to water related hazards (such as flood etc.), development-related human needs and sustainability as the major dimensions to assess water security. Whilst Lautze and Manthrilake (2012) emphasize basic needs, environment, risk management, and independence dimensions are to be considered for assessing UWS. They also suggest including a 'risk-management' indicator that is particularly linked with water related disasters (Lautze and Manthrilake, 2012). Hall and Borgomeo (2013) argue that the risk dimension is the defining attribute among all dimensions of UWS. Therefore, Lautze and Manthrilake's (2012) 'risk' indices can be interpreted as indicators (i) of not satisfying basic needs (for given proportions of time and quintiles of the population), (ii) of harmful environmental impacts, and (iii) to the reliability of water supplies from the actions of neighboring countries. Underlining the importance of risk then Hall and Borgomeo (2013, p.1), water security signifies '*the absence of intolerable risks (related to water insecurity) leads to consideration of a broad range of risks and context-specific evaluation of their tolerability*'. However, the approach has not specified the *time* dimension in their risk management indices; neither any specific limit in terms of how to deal with a risk when it emerges, nor to prevent it.

c) UWS assessment with a developmental lens

The Asian Water Development Bank (ADB) (2013) proposes five key dimensions to analyze water security at a country level scale focusing on poverty reduction in people's lives, livelihood and governance. The overall framework proposed by Asian Water Development Bank (2013) is a comprehensive approach where all the considered dimensions are related and interconnected. However, UWS is accounted exclusively from a water management perspective measuring the adequacy and efficiency of water supply, pollution management, wastewater treatment and drainage services to the urban dwellers. Other aspects of water security such as health and sanitation, resilience to water related disasters like floods or water-borne diseases are not accounted for in their urban water security measurement scheme. Similarly, the indicators for the environmental water security are derived only for the measurement of environmental health in terms of water body restoration and considerations of water as resource; other ecosystem services are not included in this scheme. According to UN Water report (2015), 95% of the urban expansion in the next decades will take place in developing and emerging countries. In Africa and Asia, the urban population is expected to double between 2000 and 2030. Between 1998 and 2008, 1052 million urban dwellers gained access to improved drinking water and 813 million to improved sanitation. However, the urban population in that period grew by 1089 million people and thus undermined the progress. Since in 2014 497 million people in cities rely on shared sanitation (UN Water, 2015), in 1990 this number was 249 million; in consequence the framework of Asian Water Development Bank (2013) lacks a detailed assessment of issues related to sanitation and hygiene at the city level scale.

d) The importance of overlapping relations of the environment and the social

One of the most widely used dimensions of UWS is environment (among others Garrick and Hall, 2014; Pahl-Wostl and Knüppe, 2016; Romero-Lankao and Gnatz, 2016). The analysis of environmental vulnerability related to water insecurity has primarily been applied to assess health hazards related to climate change (e.g., Patz and Balbus, 1996; Dickin et al., 2013; Garrick and Hall, 2014). Many of the previous studies focus either on the risk of water insecurity for the society (e.g., Grey et al., 2013) or give attention to water conflicts as a threat to international security and peace (e.g., Tignino, 2010). Water Pollution is included in this dimension as pollution of rivers and seas remains a big problem affecting especially coastal cities, where e.g. more than 60% of the Latin American population lives (UN Water, 2015). Therefore, it is fact that the risks related to water insecurity out of climatic and human-made disasters are high in low- and middle-income countries, where up to 50 % of the urban population lives in slums (World Bank, 2011). Here, social dimension of the UWS issues overlap with environmental vulnerability issues. The urban poor are vulnerable to water insecurity and related hazards due to the location of their suburbs within cities and the lack of reliable basic services and education (World Bank, 2011).

A holistic study on water insecurity needs to understand people's struggle to survive in difficult circumstances because the impact of the water insecurity stressors varies for different social groups. Different social groups have unequal access to resources, leading to unequal strengths and capabilities in coping with stressors (Udas et al., 2018). Ciurean et al. (2013) highlight effective adaptation policies for climate change that consider the assessment of social vulnerabilities through a bottom-up approach in relation to physical vulnerabilities. Leb and Wouters (2013) argue that social inequity, economic inefficiencies and unbearable environmental conditions disrupt the pathways to achieve water security, which in turn affect national security negatively. The conceptual framework presented in this chapter builds on these studies and expands on the social to better understand and assess water security issues.

e) Gender-based vulnerability and UWS

When it comes to water security, social, political, cultural and economic vulnerabilities need to be considered. Gender based vulnerability as a subset of social vulnerability is part of a process that creates

differential vulnerabilities for people belonging to different gender categories (Sugden et al., 2014; Goodrich et al., 2017). Here, it is crucial to apprehend that “gender” is not just an indicator for women and men; rather, it encompasses heterogeneity in gender categories and intersectional approaches are needed to understand which intersecting factors and positions that create vulnerabilities to water insecurity (Ravera et al 2016). It is well known that floods and droughts have an adverse gendered impact on health (WHO 2014), however, less is known about the variations within gender and the influence of other intersecting factors such as ethnicity and socio-economic on water hazards and injustice.

We also know that our relation to, use of and access to water differ according to gender, i.e. water collection is in its majority carried out by women (UN Women 2018) which means that gender matters in water security. Thus, without considering the facts of inequalities in the society and their individual impacts the inclusive character of an assessment of water security, particularly for the urban areas, are incomplete. The importance of gender in understanding water insecurity has not been analyzed to any extent in water security studies thus far, a shortcoming our framework seeks to address. We underline the importance of the intersectional position and gender to understand individuals’ and groups’ vulnerability to water insecurity. Among the issues we seek to explore is the complexity of gender and how it affects water insecurity, which we will do by opening the gender concept to include people across the gender continuum, something which has not been done so far.

f) Cultural UWS

Culture is understood as a system of shared values, beliefs, behavior and symbols that the members of society, groups or individual families use to interact with in their social environment (Spencer-Oatey, 2012). It is a comprehensive outcome of societal values, traditional practices, local belief, taboos associated with sexual orientations, gender issues as well as other differences (Schelwald and Reijerkerk, 2009; Warner et al., 2008). Social aspects affect social and interpersonal behavior and herewith the behavior related to use and views of water (Pfau-Effinger, 1998; Van Oorschot et al., 2008). Thus, these socio-cultural factors are not only constructed by social norms and interpersonal interactions but also institutionalized into policies and public institutions (Van Oorschot et al., 2008). All these aspects have only rarely been studied related to water security, something that has resulted in inadequate knowledge about how these aspects influence water security. We argue that this is crucial for the understanding how people relate to water, and different water sources (i.e. the position of the Ganges in India), who uses water, how and when water security occur. Culture is crucial to consider as it influences not only individual and group behavior, but also through its institutionalization into systems of governance affecting how water security is dealt with in different areas.

g) Politics and UWS

Water security characteristically is a political issue (Borgardi et al., 2011; Leb and Wouters, 2013) and persistent visible in transboundary conflicts (Singh, 2008; Abdolvand et al., 2015). In the case of urban areas, water security is an issue for conflicts between coexisting social, cultural, religious and political groups. It is also an issue that is dealt with by and through different levels of governance, i.e. local, regional, national and international, creating a complex web of politics of water. Here we see Politics as a determinant of water accessibility and management, as Politics relates to the way people deal with each other, select others for elected offices, form political parties, negotiate, contend with other parties, and the entire system whereby this happens. On the other hand, Governance refers to the social, economic, administrative as well as political systems that affect water’s use and management within the city. Thus, governance is a determinant of the equity and efficiency in water resource and services allocation and distribution, and ultimately balances water use between social, economic and political activities and ecosystems (Bakker and Morinville, 2013).

Water security as a key component of human security must be addressed into the assessment framework (Biggs et al, 2013; Leb and Wouters, 2013). The socio-economic and political issues of UWS that power dynamics at the international, national, regional and even local level also impact the equitable allocation of water to stakeholders, including business, communities and ecosystems (WWF, 2016). Singh (2017) argues that for a proper water resources management socio-political issues need to be considered to the same degree as technical and financial issues. Financial challenges can undermine the effectiveness of infrastructural or technological actions to achieve UWS (Singh, 2017). For example, in 2014 27% of the urban dwellers in the developing and emerging countries did not have access to piped water at home and 828 million people live in slums or informal settlements that are scattered around the cities whereas they pay up to 50 times more for a liter of water than their richer neighbors, since they often have to buy their water from private vendors (UN Water, 2015). Hence, wherever water is concerned, the effective use of the available water resources is important as water plays a crucial role for many objectives regarding the urban human habitat (Bengtsson and Shivakoti, 2015). Nevertheless, to take full advantage of such synergies requires carefully conceived cross-sectoral engagements to reach the goal of UWS, which is based on good understanding of inter-linkages between various objectives (Bengtsson and Shivakoti, 2015). In our comprehensive framework we will encompass measurements of governance and politics, both explicitly, to enable recommendations for better solutions to achieve water security for all.

4. Conceptualization of an inclusive framework to quantify urban water security

The inclusive assessment framework for UWS needs to address the complex and interwoven *environmental, social, cultural, political, economic, governance and technologic* dimensions to create a tool that can measure the complex web of issues contributing to UWS. The supply and usage of quality water as a renewable resource at the minimum replaceable limit to fulfill the population's need/demand needs to be considered as a basic human right. Therefore, availability and accessibility of adequate water as well as affordable to all must be accounted for. The next important issue to be considered is the urban ecosystem services at a minimum depleting rate of the non-renewable, where allocation of enough water is necessary to maintain a sustainable urban ecosystem service. Waste water management concerns the alarming levels and concentration of pollutants generated in these growing urban agglomerations specifically for the poor areas within and outside of the main city due to the lack or poor waste management. Thus, properly planned and necessary infrastructural and technological capabilities concerning water borne diseases and natural hazards like flood. A management response from governance and institutions for the proper management of water resources (Bakker and Morinville, 2013).

Issues of concern for conceptualization of the inclusive framework

The measurement approaches for a quantitative assessment of the sustainability of urban water systems as provided by the literature (see Appendix 2) focus predominantly up to a meso (regional) level. Therefore, the variations within a city level scale, such as neighborhood effects, intersectional issues and cultural aspects within the urban ecosystem services were missed. Case specific quantitative index models, which reflect coupled human-water-system dynamics in comparative temporal and spatial scales are rare to find. Beyond, the trade-offs between different water issues related to ecosystem services as well as socio-economic potentialities need to be addressed in selecting indicators and developing overall indices.

The assessment approaches listed in Appendix 2 are primarily looking at the sustainability of urban water systems. The focus is hence distributed either on the environment or the policy or the urban water system services issues more than on holistic procedure. The different measurement approaches for sustainability (Appendix 2) and their compatibility with the dimensions and issues are compiled in Table 1:

Table 1: Compilation of approaches, dimensions and issues of Urban Water Security.

Approach	*Dimensions							**Issues									
	Env.	Soc.	Cult	Pol.	Econ.	Gov.	Tech.	Av	Ac	HR	WQ	WM	NH	WD	Mg	Tech	UES
Integrated Urban Water System Modelling (IUWSM) (Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013)	X				X	X	X	X			X	X				X	
United Nations Commission on Sustainable Development (UN-CSD) (UNCDS, 2001)	X	X			X	X		X	X		X		X	X	X		X
Ecological Network Analysis (ENA) (Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013)	X				X			X	X							X	X
System Dynamics (SD) (Baki et al., 2012; Sahin and Stewart; 2013)	X	X	X		X	X	X	X							X	X	

Territorial Material Flow Analysis (UM-MFA) (Ayers and Ayers, 2002; Codoban & Kennedy, 2008; EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newmann et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005)	X					X	X	X	X	X							X		
Water Mass Balance (UM-WMB) (Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009)	X						X	X	X	X							X	X	
Life Cycle Assessment (LCA) (Fagan et al., 2010; Lane et al., 2015; Lundin, 2003)	X					X	X	X	X	X			X	X	X	X	X	X	
Water Footprint (WF) (Hoff et al., 2014; Vanham, 2012)	X	X				X			X	X	X	X					X	X	
Environmentally Extended Input-Output Analysis (EIO) (Lenzen, 2009; Lenzen and Peters, 2009)	X	X				X													
Aqueduct water risk indicators (Gassert et al., 2013)	X	X				X	X	X	X	X			X				X	X	X
Index of water security threats (Vorosmarty et al., 2010)	X	X				X	X	X	X	X							X	X	
Pressure-State-Response (PSR) (OECD, 2004; OECD, 2003)	X	X				X	X	X	X	X			X	X	X	X	X	X	

Driver-Pressure-State-Impact-Response (DPSIR) (Marsili-Libelli <i>et al.</i> , 2004; Pirrone <i>et al.</i> , 2005; WWAP, 2006; WWAP, 2002)	X	X			X	X	X	X	X			X	X	X	X	X	X
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*Dimensions : Env: Environmental; Soc: Social; Cult: Cultural; Pol: Political; Econ: Economics; Gov: Governance; Tech: Technology; **Issues: Av: Availability; Ac: Accessibility; HR: Human Rights; WQ: Water Quality; WM: Waste Management; NH: Natural Hazards; WD: Waterborne Diseases; Mg: Management; Tech: Technology; UES: Urban Ecosystem Services

Considering culture as a dimension

To include social indicators which are not commonly included in water security research to provides an improved tool to assess UWS and is the precondition to develop sustainable strategies that enable water security for all. Culture affects the access, use, consumption and, importantly, vulnerabilities when it comes to water security. For example, there are clear differences of attitudes towards the use of water, sanitation and hygiene facilities and the handling of excreta between diverse cultures. Despite an instinctive repulsion towards excreta, different cultures influence different attitudes towards handling of excreta and maintenance of personal hygiene in terms of water usage (Warner *et al.*, 2008). Cultural values related to gender affects who uses water, how, where and when, i.e. who washes the clothes, using water from where and at what time. Thus, cultural values, gender and water insecurity are tightly interlinked and need to be explored and included in the measurement tool. Culture affects water security also in terms of how we see and define our water sources, e.g. the meaning of the river Ganges in India. In addition, culture is institutionalized into governance and governmental institutions. In consequence, we need to identify how cultural norms may enable or hinder UWS as a part of the comprehensive UWS assessment.

Water justice and gender

The approaches of urban water security to date mainly focus on the assessment of the urban water system and its sustainability from either environmental or economic perspectives (Tables 1). However, as the UNESCO proposal for the global sustainable development goals (SDGs) on water-Target 1 claims;” universal access to safe drinking water and sanitation for all” and, thus, points out that the right to clean water is fundamental. Violations of the right to water can be traced back to injustices including poverty and other social exclusion issues (Leb and Wouters, 2013). Overall, the role of gender in water insecurity issues is crucial. In the social sciences it is recognized through stuides on how gender shapes issues of water access, use, governance, and adaptation to water insecurities and environmental crises (Alston 2006; Fletcher, 2018; Sommer *et al.* 2015, WWAP, 2015; UNEP 2016). Gender roles and relations are important explanatory issues for UWS as water access, needs, and uses are all shaped and influenced by gender roles and are in relationship to any given society (Ray, 2007; Wallace and Coles, 2005). The importance of gender is further underlined by the fact that water security risks are higher amongst women and third gendered people (Demetriades and Esplen, 2010; Denton, 2002; MacGregor, 2009); in consequence women and third-gender people are often more vulnerable and exposed to risks related to water (Fletcher, 2018; Sommer *et al.* 2015). This includes a high vulnerability of women and third gendered people due to natural disasters like floods and droughts (Fletcher, 2018). Accordingly, urban water security cannot be achieved without accounting for gender equality and social inclusion within an assessment framework (Pangare, 2016). The inclusion of gender mainstreaming in UWS research is an opportunity to involve women and third gendered people in the design, planning, implementation of water services, management of natural resources, and in the development of disaster risk reduction strategies; gender-insensitive policies will only impede global efforts to eradicate poverty and achieve water security. Investing in the infrastructure needed to provide adequate water and sanitation facilities can also sharply reduce health costs and improve

productivity (Pangare and Pangare, 2008). Previous studies in different disciplines have highlighted that vulnerabilities and experiences of water security vary according to a range of socio-economic issues (Demetriades and Esplen, 2010; Denton, 2002; MacGregor, 2009; Pangare, 2016). The approach of the proposed framework addresses the role of poverty and gender and the combination of intersectional vulnerabilities by including variables related to gender issues rarely included in empirical studies on water security.

Including governance measurements

Water crisis is not always or only due to physical scarcity of water but is also frequently due to inadequate or inappropriate water governance (AWDO, 2007). When it comes to urban water governance, different aspects need to be considered. First, urban water governance is related to and influences the extent to which the goals of UWS can be reached. Secondly, it influences and is directly related to the management and coordination of UWS. In consequence, urban water governance is a crucial dimension to be included in any UWS assessment scheme. We will include indicators directly related to the organization and management structures and we will explore other processes in which governance matters, such as in how successfully achieving UWS, and to what extent urban water governance contributes to higher or lower levels of UWS. In line with the comprehensive approach pursued stakeholders in different positions (e.g., NGOs, civil servants, and people living in water insecure areas) need also to be included to identify the ways in which urban water governance matters. For example, due to increasing urbanization, the municipal water demand in Chinese cities are projected to grow 70% in 2030 (Wang et al., 2017). Although China's need for renewable freshwater continues to escalate, availability is barely one-third of the world's average. Shanghai falls among China's 36 worst cities regarding water quality (Zhen et al., 2017), and between 2010-2012 it was reported by the city's water census that 3% of local surface water was clean for fish farms or household use. Shanghai typifies the water governance problem China is facing from one mega city to the next and, hence, backs the urgent need for a comprehensive UWS assessment framework for the policy makers.

Achieving sustainable UWS

Sustainability analysis to achieve UWS needs to account for the interrelationship between water systems and economic production in a way that includes health and welfare. Reviewing various approaches related to UWS and sustainability it becomes evident that there are understated assumptions regarding what UWS means and how it can be achieved. For example, United Nations Commission for Sustainable Development (2011) considers sustainable development as directly compatible with economic growth. Hueting and Reijnders (2004) oppose this and consider sustainable development as an assumption 'neither demonstrated nor plausible'. Otherwise, any action taken by a city administration to augment the supply and ensure the sustainability of the urban water system can have an opposite effect, such as increasing the gap between demand and supply, or producing more pollution. Moreover, low or absence of proper maintenance of the storm-water management system can have a stronger adverse effect in slum areas than other parts of the city. It affects supply and water quality which raise the insecurity of water in the city. These social, environmental and economic effects that affect the city's water security are vital to include in measurements to understand what actions should be considered to maintain a water secured city. Hence, the concept of risk should be deployed across "the environmental, social, and medical sciences", and therefore the framework should be compatible with an interdisciplinary approach to analyze UWS (Hall and Borgomeo, 2013).

In the proposed conceptual framework, social equity, cultural, political and economic aspects are considered for the development of the resource management plans (Leb and Wouters, 2013). Underlying this concept is also an acknowledgment that it is difficult to separate the social and cultural aspects from each other. They are intertwined, and their combination impacts the water security in a society – for example, through sanitation and hygiene behavior of a certain population. The relationships between culture and policies in each society are factors that have been studied in other public policy areas, such as welfare

policies (Hiroko et al, 2011). Including gender values and norms in an UWS assessment matrix, and to account for how it influences water security and the vulnerability and behavior related to water security is deemed crucial in the proposed conceptual framework. Van Oorschot et al. (2008, p. 11) argue that culture affects and combines “the short-term effects of social interactions at the micro level with the more enduring cultural values and models at the macro level of society”. Accordingly, it becomes crucial to incorporate measures that can start unpacking and understanding these complex interactions, and to take them into account when designing policies and campaigns that can help to achieve UWS. In consequence, the proposed framework will include intersectional measurements and will, thus, include questions considering ethnicity/origin/race and socio-economic vulnerability to water insecurities. This concept also revisits factors that can enhance our understanding of a person or group’s vulnerability in relation to UWS.

The need for new data at city levels

There is an intrinsic importance of baseline data collection for the appropriate assessment of water security. Achieving water security is definitely a paradigm shift for emerging and developing countries from the ways this valuable resource is being ‘managed’ so far. Despite the deep-rooted affinity to underestimate the necessity of research of water security at all levels, the value for baseline data collection remains indispensable for the sustainable management of the water resources for the security of the inhabitants of a country. It is also crucial to include city level data in analyses of water security to ensure a more comprehensive understanding of what drives and determines water security, such as availability and accessibility of quality water at the household level. Coherent collection of long-term data coupled with local knowledge is the priority for such researches. The primacy of institutional responsibilities for data collection, the level of existing data availability, and data sharing options between different institutions need to be addressed. Also, these aspects are important frame conditions to provide appropriate recommendations that can ensure an appropriate data collection technique as well as appropriate mechanisms for data sharing. It has therefore been decided that intensive survey at household level and existing data from the authorities from the lowest level will be required and henceforth, combined to create data that satisfy the need for detail that is required to create an improved UWS index.

Conceptualizing the inclusive framework for urban water security assessment

The formation of our quantitative inclusive framework is based on the ecosystem services and system approach. The concept of urban water security, here, emphasizes the basis of sustainability of ecosystems, focusing on reducing the probability or risk of ecological disaster caused by human-induced stresses. To assure long-term sustainability, UWS assessment needs to be addressed from an integrated social-ecological systems perspective (Pahl-Wostl and Knüppe, 2016). The main spirit of all the definitions of water security published so far (Appendix 1) maintains a trade-off between usage and management of water resource for both the human and the environment (Stewart-Koster and Bunn, 2016; Grey and Sadoff, 2007; Naiman et al., 2002). Therefore, managing the conflict between supply (enough quality and quantity) and risk (anthropogenic and environmental) to the provision of water ecosystem services in an urban area is a challenge for the water scientists and managers (Stewart-Koster and Bunn, 2016). Pahl-Wostl and Knüppe (2016) argue that the ecosystem services need to be served as a connection for integrating fragmented institutional settings to support and negotiate about trade-offs for water security without jeopardizing the environment. From this point of view, urban ecosystem services principles are central to define an inclusive and holistic sustainable approach for the quantification of urban water security. Thus, a modified version of Driver-Pressure-State-Impact-Response (DPSIR) as a framework is proposed here to assess the dynamic interactions and feedback effects between water and people in an urban area.

This quantitative framework will encapsulate the urban water security dimensions and factors (Figure 1) of a system approach (Driver, Pressure, State, Impact and Response) into three major matrices: Pressure (Driver & Pressure), Process (State) and Impact (Impacts & Responses) (Figure 2) ‘Pressure’ matrix will

deal with the Driver and Pressure factors of the problems, the 'Process' matrix will comprise the State factors and the 'Risk' matrix will involve Risks and Response factors from the both physical and socio-economic dimensions of UWS. Rather than setting a simple DPSIR framework, we here adding to the DPSIR a more integrated and bottom-up approach to assess the scenario quantitatively. This conceptual framework will include the most affected and vulnerable groups for better understanding of the issues related to UWS. The concept behind is based on the issues these groups are facing and identify in their answers as well as the results of the bio-physical data analyses. The issues are then put together into three main queries:

- 1) What are the drivers and pressure factors on the water services,
- 2) What are the state (i.e., uses and consumption) factors of the water resources available and supplied and,
- 3) What are the impacts and associated risks and the responses from the governance and instructional perspectives.

The answers are expected in numbers and will include all the dimensions (and issues) outlined in figure 1. In this way, the mitigation decision will be easier to take than under the present conditions. The framework of the quantitative indicator system will have to include the following measurements:

- ***Pressure matrix***

The Pressure Matrix will be cover Drivers and Pressures associated with the urban water system of a city which determine the ultimate security from water for the environment and the citizens. *Driver* factor (D) illustrates the social-economic and political scenarios in the communities in and around the city as well as the consistent changes in lifestyle, consumption, and production patterns. Decadal population growth, population density, gross domestic production, per capita income, Gini coefficient, and other factors that directly or indirectly influence urban ecosystem services and over all urban water security will be included.

Pressure factors can be congregated in bio-physical and socio-economic aspects. *Pressure* indicators (P) try to find the reason behind the status of the water security in a city, measuring the impacts that human activities exert on urban water systems. Special focus is on the effect of human activities on ecosystem services and on the water demand (quantity) and increasing exposure to water-related hazards (quantity, quality). Conflicts between water availability and accessibility often occur in any mega cities in developing and emerging countries despite of having an adequate amount of fresh water resources available. As a result, the total water-resource utilization, water-quantity ratio of inputs and outputs in a city area, per capita water-resource use, and ecological water demand and related data are required to be included in the index of UWS evaluation. The gap between demand-supply related to physical, social such as caste, religions, sexual minority issues should also be considered. In addition, some specific socio-economic pressures, such as the presence of water-intensive industries, widespread open defecation or gender issues in access to water and sanitation need to be included as pressure indicators. Land subsidence due to unsustainable groundwater abstraction, huge building construction, encroachment of wetlands suitable for urban expansion need to be considered as effects causing water stress in cities, both in terms of flood problems and water scarcity. Beyond, in case artificial drainage systems occur, inadequate environmental flow in and around the city also need to be considered as pressure for the urban water security.

- ***Process matrix***

The Process matrix expresses what is happening to the state at the various scales of city's urban water security status. The Process matrix will cover the *State* indicators (S) of the urban water security which

reflect the ecological health as well as socio-economic status of the city. Regarding water quality, pollutant emissions are the main stressor. Therefore, various sources of pollutants should be considered. Water quality indicators can be obtained from conventional water monitoring and sampling. The State indicators will concern the infrastructure to manage the quality and quantity of water as well. The quantity of water in a city can be described in terms of water stocks and flows and exchanges with areas outside the municipal boundaries considering ground and surface water. Groundwater extraction from wells within and outside municipal boundaries is an important source for urban water supply. Surface water and groundwater quality will be compared to ambient water quality standards including both, chemical and biological pollutants. Biological contamination is particularly relevant for shallow groundwater wells, often used by households in cities with inadequate water supply systems, which are contaminated from leaking sanitation infrastructure (leaking sewers, septic tanks, latrines, etc.). Water supply infrastructure from the abstraction points to the household-levels, sanitation infrastructure and flood protection infrastructure need to be considered when evaluating the state of urban water infrastructure. Relevant indicators for the state of the infrastructure include coverage of water supply systems in terms of connection rates and supply capacity, drinking water quality standards, percentages of wastewater collection and treatment, distinguishing between primary, secondary and tertiary treatment, leakages in drinking water supply and sewerage systems, and adequacy of storm water and flood protection infrastructure. Lastly, there is a strong link between solid waste management in a city and the amount of garbage in streams, canals and wetlands. Therefore, indicators related to the site, and treatment facilities associated with city's solid waste management is an integral part of the Process matrix.

- ***Impact matrix***

The Impact matrix will cover a significant number of indicators for a comprehensive analysis of impact and responses from the government and non-governmental institutions associated with the urban water systems. *Impact* indicators (*I*) characterize the changes in the state which reflect on the functioning of the urban water system from all individual, societal, institutional and ecosystem perspectives. It can be bio-physical (e.g. floods etc.) or societal factors (e.g. accessibility due to the societal discrimination) which affect the quality and quantity of ecosystem services and, certainly, the livelihood of the inhabitants. The *Impact* factor expresses the risks accompanying the manifestation of insecurity from water in a city in terms of disasters or scarcity. Unlike, State indicators, Impact indicators will not only focus on the bio-physical part the entire water system in a city but will also include the provision of risks and problems associated with water borne diseases. Risks related to water quality and sanitation which are related to the physical infrastructure and financial condition of the city governance for managing uncertain calamities like floods are also needed to be included in the assessment. For cities like Kolkata, the risks related to urban water system are also not linear in character. There are possibilities to have malfunctioning of water supply system in terms of breaking down during high demand period or is contaminated due to the leakage. These aspects along with the affordability for poorer households, should be considered for the assessment as risks to UWS.

Response indicators (*R*) are majorly decisions and policies which are taken repetitively to act for or against the impacts on the water security. They control the *drivers*, decrease pressures and reduce negative impacts of malfunctioning urban water services and functions (Sekovski et al., 2012) through regulation, prevention or mitigation to maintain/restore the state of the sustainable urban water security. Response towards gender mainstreaming in the policy related to urban water management will also be taken into consideration here. The focus of these response indicators should not only be on the governmental response while societal response is equally important. Generally, urban water systems are complex and dynamic, response indicators should cover the innovative and developmental decisions taken for all technical, institutional and organizational dimensions considering their own timeframes and scopes. Further, many responses require dealing with uncertainty and ambiguity, e.g. when it concerns policy-making for future climate change issues. Therefore, a significant number of indicators

must cover all the existing policy or decision-making focused on future uncertainty for resilient, adaptive and robust urban water systems for sustainable functionality.

To design a resilient and valid quantitative assessment framework, we need to focus on the sustainable water future of the urban area from social, economic and environmental perspectives including the management of infrastructure required to achieve sustainable urban form and structure. UWS issues are linked with different urban ecosystem services which signifies the sustainability of the quality of life. This sustainability is reliant upon input and output of the urban area. The urban input-output system depends on the lifestyles (according to the socio-economic standard and their” needs/demands”) and the usage/ accessibility of technology to control the consumption of resources and creation of wastes (including pollution). Therefore, urban water and sustainability measurement approaches vary with the different value-added activities in different socio-economic pockets of a single urban area depending on their resource-consumption rates and the production of the wastes and pollution. Systematic measurement of these different urban characteristics in different socio-economic and environmental compartments of an urban area are necessary to identify and assess the water resource efficiency. Our proposed assessment framework is inclusive in character because it focuses not only on the physical/environmental side of the urban water system but also on socio-economic, political and cultural aspects that are related to and impact water security. Overall the proposed framework is conditioned to add to our understanding of barriers impeding UWS for all communities at household level.

5. Conclusions

UWS is a complex system where a multiple of actors and factors are at play. This makes addressing water insecurity issues a difficult task. It is also a task where we need to disentangle this web of factors to create strategies capable of addressing the issues impeding a water secure future. This chapter reviewed existing research and identified gaps. A multitude of approaches to measure UWS available. Only a few studies have identified the need for water security as the main factor for growth and sustainability for the society. The proposed assessment framework has been conceptualized to facilitate active discussion and mitigation approaches between participating experts and the stakeholders. This framework is proposed to consider the strategies for cities that assures water security for all but not in exchange for ecological integrity. This inclusive conceptual framework needs to be developed at a micro level to identify the best measurements for a holistic measurement tool. On this basis it can be scaled up to regional and national levels to be incorporated in planning and management decisions. The importance to engage wider public in debates on emerging scientific issues such as UWS is to provide a successful adaptive plan for capacity building and making the society more resilient to the climate change related disasters in developing and emerging countries. It also underlines the importance and relevance of science for policies. Through this strong linkage, it will be ensured that the citizens keep informed on the development and the role of the scientists. Simultaneously, the policy makers will play in broadening the understanding of the needs in making the city more sustainable providing the assurance to achieve water security for all.

The focus of the proposed integrated assessment framework of UWS is to associate and amalgamate human-oriented and environmental perspectives. The focus of the proposed conceptual framework will be on each key dimension to achieve goals of UWS. The bottom-up concept of the assessment will foster the idea of integration through a decentralized and holistic management technique. Integration of local ideas will be involved in the procedure to touch the various aspects of needs, demands, risks and developmental perspectives. This way, the ‘integration’ will bridge ‘people, planet and profit’.

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Appendix 1: Definitions of Water Security

1. Water Security is ‘a situation of reliable and secure access to water over time. It does not equate to constant quantity of supply as much as predictability, which enables measures to be taken in times of scarcity to avoid stress.’ (Applegren, 1997)
2. A comprehensive definition (of Water Security) goes beyond availability to issues of access. Access involves issues that range from a discussion of fundamental individual rights to national sovereignty rights over water: It also involves equity and affordability, and the role of states and markets in water's allocation, pricing, distribution and regulation. Water security also implies social and political decision-making on use - the priority to be accorded to competing household, agricultural or industrial demands on the resource. (Gutierrez, 1999)
3. Water Security is ‘a condition in which there is a sufficient quantity of water, at a fair price, and at a quality necessary to meet short and long term human needs to protect their health, safety, welfare, and productive capacity at the local, regional, state and national levels.’ (Witter and Whiteford, 1999)
4. Water Security ensures ‘every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced.’ (GWP, 2000)

5. Water security means that every person has access to enough safe water at an affordable cost to lead a healthy and productive life and that the vulnerable are protected from the risks of water related hazards (Ministerial Declaration of The Hague, 2000).
6. Household water security is ‘the reliable availability of safe water in the home for all domestic purposes.’ (WHO, 2003)
7. Water security is a situation of reliable and secure access to water over time. It does not equate to constant quantity of supply as much as predictability, which enables measures to be taken in times of scarcity to avoid stress. (Abrams, 2003)
8. The water security can be defined as the ability of different section of population to access sufficient quantities of clean water to maintain adequate standards of food, sanitation, health and production of goods (Institute for the Analysis of Global Security, 2004)
9. There are three important elements of “water security”: 1 Water security is based on three core freedoms: freedom from want, freedom from fear and freedom to live in human dignity; 2 Ensuring water security may lead to a conflict of interests, which must be capable of being identified and effectively dealt with at the international, national and local levels; 3 Water security, like water, is a dynamic concept, and one that needs clear local champions and sustained stewardship. (Wouters, 2005)
10. Water security means the ability to supply water, according to a specified quality, to homes and industry under conditions satisfactory to the environment and at an acceptable price. The definition of water security includes: (a) population-wide security, that is, everyone can obtain secure water for domestic use; (b) economic security, namely water resources can satisfy the normal requirements of economic development; (c) ecological security, namely water resources can meet the lowest water demands of ecosystems without causing damage. (Xia et al, 2006)
11. Water security is linked to a safe water supply and sanitation, water for food production, hydro-solidarity between those living upstream and those living downstream in a river basin and water pollution avoidance so that the water in aquifers and rivers remains usable, i.e. not too polluted for use for water supply, industrial production, agricultural use or the protection of biodiversity, wetlands and aquatic ecosystems in rivers and coastal waters. (Falkenmark, 2006)
12. Water security is ‘the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies.’ (Grey and Sadoff, 2007)
13. Water security is ‘availability of, and access to, water sufficient in quantity and quality to meet the livelihood needs of all households throughout the year, without prejudicing the needs of other users.’ (Calow *et al*, 2010)
14. Water security is just what we choose to eat [and] nothing to do with the environment or science etc.’... ‘Water security is linked with food trade – as “energy security” is (more obviously, perhaps) linked with oil trade.’... ‘Secure use of water is defined by political processes. Water security is achieved outside the watershed (in the “problemshed”). (Allan, 2011)
15. Water security is ‘sustainable access, on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health.’ (Norman *et all*, 2011)

16. Social and physical processes combine to create or deny water security. Sustainable water security is interpreted as a function of the degree of equitability and balance between interdependencies of the related security areas, played out within a web of socioeconomic and political forces at multiple spatial levels... The “web” of water security identifies the “security areas” related to national water security. These include the intimately associated natural “security resources” (water resources, energy, climate, food) as well as the security of the social groups concerned (individual, community, nation). The “web” recognises the interaction occurring at all spatial scales, from the individual through to river basin and global levels. In this sense, an individual’s water security may coexist with national water insecurity, as in the case of wealthy farmer-sheikhs with the deepest wells (who may be temporarily water secure) in the dry highlands of Yemen (which is not, overall, water secure). (Zeitoun, 2011)
17. Water security is essential for human access for health, wellbeing, economic and political stability. It is essential to limit risks of water- related hazards. A complete and fair valuation of the resource, sustainability of ecosystems at all parts of the hydrologic cycle and an equitable and cooperative sharing of water resources is very necessary. (Water Aid, 2012)
18. Societies can enjoy water security when they successfully manage their water resources and services to – 1) satisfy household water and sanitation needs in all communities; 2) support productive economies in agriculture, industry, and energy; 3) develop vibrant, livable cities and towns; 4) restore healthy rivers and ecosystems; and 5) build resilient communities that can adapt to change. (ADB, 2013).
19. Water Security is defined as the capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards -- floods, landslides, land subsidence,) and droughts. (UN Water, 2013)
20. Water Security is the ‘sustainable use and protection of water resources, safeguarding access to water functions and services for humans and the environment, and protection against water-related hazards (flood and drought)’. (Wheater and Gober 2013).
21. The capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards – floods, landslides, land subsidence, and droughts (UNESCO-IHP, 2017).

Appendix 2: A summary of key approaches for quantitative assessment of sustainability of urban water systems

Category	Approach	Objective	Features	References
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Urban Water System Modelling	Integrated Urban Water System Modelling (IUWSM)	Quantification of water flows through urban water infrastructure, i.e., water supply, drainage, wastewater etc., to manage supply against demand or plan infrastructure	Bottom-up simulation of the volumes of water managed by the urban water system, to achieve a supply-demand balance of the water system	Behzadian and Kapelan, 2015; Last, 2010; Makropoulos et al., 2008; Mitchell et al., 2001; Rozos and Makropoulos, 2013; Urich et al., 2013; Venkatesh et al., 2014; Willuweit O'Sullivan, 2013
Sustainability frameworks	United Nations Commission on Sustainable Development (UN-CSD)	Assessment of a policy for Reporting, Comparison and Decision-Making towards sustainability	Consideration of 4 dimensions of sustainability, namely Environmental, Social, Economic and Institutional	UNCDS, 2001
Complex systems approach	Ecological Network Analysis (ENA)	Quantifies indicators that represent the relationships between components of the urban water system to characterize how the system functions	Top-down collation of secondary data for anthropogenic water flows between socioeconomic components of the urban water system into input-output tables, from which system-wide performance indicators are generated	Zhang et al., 2010; Bodini et al., 2012; Pizzol et al., 2013
	System Dynamics (SD)	Quantifies trends in anthropogenic urban water flows under varying socioeconomic parameters	Bottom-up dynamic simulation of the anthropogenic water flows under changing variables, based on inter-relationships and feedback loops	Baki et al., 2012; Sahin and Stewart; 2013

Urban Metabolism	Territorial Material Flow Analysis (UM-MFA)	Quantification of city-scale water flows (alongside other resource flows), for monitoring change over time and benchmarking between cities and urban typologies	Top-down collation of secondary data for centralized water flows (total and per capita potable water inflows and wastewater outflows), as part of a wider MFA of all urban resource flows	Ayers and Ayers, 2002; Codoban & Kennedy, 2008 EIU, 2011; Kennedy et al., 2007; Kennedy et al., 2015; Mollay et al., 2011; Newmann et al., 1996; Newton et al., 2001; Pina and Martinez, 2014; Singh et al., 2009; Wernick and Irwin, 2005
	Water Mass Balance (UM-WMB)	Quantification of city-scale water flows and metabolic performance indicators, for visioning and for screening improvement opportunities	Top-down collation of secondary data for all water flows (anthropogenic and natural), and changes in storage, to achieve a water mass balance of the urban entity	Bhaskar and Welty, 2012; Chrysoulakis et al., 2013; Kenway et al., 2011; Marteleira et al., 2014; Thériault & Laroche, 2009
	Life Cycle Assessment (LCA)	Quantification of environmental impact indicators across the life cycle of urban water systems, for understanding their wider environmental implications	Bottom-up estimates of resource inputs to, and waste/pollutant outputs from, all processes in the life cycle of urban water services followed by characterization of their impacts	Fagan et al., 2010; Lane et al., 2015; Lundin, 2003
Consumption approach for Bio-physical Accounting	Water Footprint (WF)	Quantification of indirect water required to produce goods and services consumed by the city or its inhabitants	Bottom-up estimates of single metric of water extracted from the global hinterland, representing the water required to produce the goods and services consumed by	Hoff et al., 2014; Vanham, 2012

			urban dwellers	
	Environmentally Extended Input-Output Analysis (EIO)	Quantification of economic water flows (and other resources) through economic supply chains	Top-down collation of economic flows from economic input-output tables are multiplied by virtual water use associated with those economic exchanges	Lenzen, 2009 Lenzen and Peters, 2009
Risk based approach	Aqueduct water risk indicators	Quantification of the coincidence of hazards at high resolution	Key Dimensions are Chronic water stress, flood, drought/seasonal variability, environmental degradation, inadequate water supply and sanitation, and the role of institution and infrastructure	Gassert et al, 2013
	Index of water security threats		Key Dimensions are Chronic water stress environmental degradation, and infrastructure	
System approach	Pressure-State-Response (PSR)	Quantification of environmental progress and performance with international comparison. Monitoring policy integration.	Describes the causal chain of an effect considered as negative for sustainability. Four kinds of descriptive indicators are: 1) Core set 2) Key Indicators 3) Sectorial Indicators	OECD, 2004; OECD, 2003

			and 4) Decoupling set	
	Driver-Pressure-State-Impact-Response (DPSIR)	Assessment of the sustainable development (SD), making science understandable to the public and demand management for SD	Descriptive indicators, showing the state of water resources and its links with diverse water related issues: 1) Basic indicators 2) Key indicators 3) Developing indicators and 4) Conceptual indicators	Marsili-Libelli <i>et al</i> , 2004; Pirrone <i>et al</i> , 2005; WWAP, 2006; WWAP, 2002