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City Blueprints: baseline assessments of water management and climate change in 45 cities

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Abstract Climate change and urbanization are among the most significant trends of the twenty-first century, affecting global natural resources such as water, economic development and human well-being. The growth of the world population will be absorbed by the cities. The necessity of cities adapting to these trends calls for radical changes in urban water management. In this paper, baseline assessments, i.e., City Blueprints, have been carried out for 45 municipalities and regions in 27 countries, mainly in Europe. The assessments showed that cities vary considerably with regard to their water management. This is also captured in the Blue City Index® (BCI), the arithmetic mean of 24 indicators comprising the City Blueprint®. Theoretically, the BCI has a minimum score of 0 and a maximum score of 10. The actual BCIs in the 45 cities and regions varied from 3.5 (Kilamba Kiaxi in Angola) to 8.5 (Helsingborg in Sweden). The BCI was positively and significantly correlated with the gross domestic product per person, the ambitions of the local authorities regarding water management, the voluntary participation index and governance indicators according to the World Bank (2013). The study also demonstrated a very significant correlation between the BCI and the University of Notre Dame Global Adaptation Index. The impacts of water scarcity and floods in cities are discussed. It is concluded that cities in transitional and developing countries are particularly at risk.

Keywords Blue City Index® · Resilient cities · Water governance · Water scarcity · Climate adaptation

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1 Introduction

Management of fresh water resources is of critical importance to healthy social, economic and political well-being of a society. Stresses exerted on the world's water resources by the increasing demand from growing populations with changing consumption patterns, the destruction of water quality from pollution as a result of poor environmental management, and climate change are placing water increasingly higher on the international agenda (UNEP 2013; European Commission 2012; Hoekstra and Wiedman 2014; World Economic Forum 2014). These megatrends pose urgent water challenges, particularly in cities (Engel et al. 2011; SIWI 2012; Van Leeuwen 2013; Chong 2014; McDonald et al. 2014).

In many parts of the world, water systems have been unable to keep up with the rapid urbanization. Cities by their nature spatially concentrate the water demands of many people into a small area, which by itself would increase stress on finite supplies of available freshwater near cities (Grant et al. 2012; Van Leeuwen 2013; McDonald et al. 2014). The UN estimates that between 2011 and 2050 the world population will grow from 7 to 9.3 billion and that the population in cities will increase from 3.6 to 6.3 billion, while the number of people living in rural areas will decline. This means that the growth in the world population will be absorbed by the cities. In the next few decades, we will experience the most rapid urban growth in human history. Together with the migration from rural areas to the cities, during this period more than 200,000 people—a day—will need to find a new place to live in an urban environment (UN 2012). This will be accompanied by strong growth in urban water demands, especially in East and West Africa, Latin America and Asia (Dobbs et al. 2011, 2012).

Cities are the major problem holders, but active civil societies including the private sector with visionary local government can cope with water challenges (European green City Index 2009; European Commission 2015). It requires a long-term strategy, a bottom-up approach and collaboration among cities and regions by sharing best practices (Philip et al. 2011). Such learning alliances of cities can facilitate rapid and cost-effective implementation. This is needed as the time window to improve urban water cycle services (UWCS) is narrow and rapidly closing (Van Leeuwen 2013; European Commission 2015). A report from the European Environment Agency (EEA 2012) warns that cities are particularly at risk from climate change and that delaying action to adapt will be much more costly in the long term than immediate action. In fact, the longer political leaders wait, the more expensive adaptation will become and the danger to citizens and the economy will increase.

Our work is carried out in the context of the European Innovation Partnership on Water (EIP Water). EIPs help to pool expertise and resources by bringing together public and private actors at EU, national and regional levels. The overall objective of the EIP Water is to support and facilitate the development and implementation of innovative solutions to deal with the many water-related challenges Europe and the World are facing, as well as to promote economic growth by bringing such solutions to the market in Europe and further afield (European Commission 2015). The City Blueprint action of EIP Water is an action on water governance. The main goal is city-to-city learning, i.e., to establish a network (learning alliance) of European cities to share their best practices on UWCS in the transition toward more sustainable and resilient UWCS in their municipality or region (European Commission 2015).

In previous reports and publications, we have presented detailed reviews of the sustainability of UWCS in cities such as such as Rotterdam (Van Leeuwen et al. 2012), Dar es

Salaam (Van Leeuwen and Chandy 2013), Hamburg (Van Leeuwen and Bertram 2013), Amsterdam (Van Leeuwen and Sjerps 2015a), Istanbul (Van Leeuwen and Sjerps 2015b), Ho Chi Minh City (Van Leeuwen et al. 2015) and Melbourne. This paper summarizes the results of the assessments of all 45 municipalities and regions assessed so far.

2 Methodology

In order to create awareness and to ensure sustainable futures for cities, we have developed a simple baseline assessment methodology to assess the management of UWCS in cities. We have included indicators based on a variety of approaches such as the water footprint (Hoekstra et al. 2012), urban metabolism, ecosystem services and governance (Van Leeuwen et al. 2012). The methodology has been developed at KWR Watercycle Research Institute and has been further refined and applied in the EU TRUST project (Van Leeuwen and Marques 2013). Later, it became an action on its own in the EIP Water (European Commission 2015). Constructive feedback from the municipalities and regions has resulted in a gradual improvement, following a learning-by-doing approach. This has helped us to further improve the City Blueprint Questionnaire and the City Blueprint methodology (European Commission 2015). The result allows a city to quickly understand how advanced it is in sustainable water management and to compare its status with other leading cities and to develop a long-term strategic planning process to improve its performance (Fig. 1). The City Blueprint® is both a process and tool. The basic output is a simple radar chart.

This baseline assessment or City Blueprint® can be used as a first step to benchmark UWCS in cities (Philip et al. 2011; Van Leeuwen and Chandy 2013) and may help: (1) to communicate a city's UWCS management performance and exchange experiences, (2) to select appropriate water supply, sanitation and climate adaptation strategies, (3) to develop technological and non-technological options as future alternatives for the water cycle, where several possible changes in the use of technology, space and socioeconomic scenarios can be introduced. This should finally lead to: (4) a selection of measures, including an evaluation of their costs and benefits under different development scenarios, and how to integrate these in long-term planning on urban investments (Van Leeuwen 2013; European Commission 2015; OECD 2015).

The City Blueprint® is an interactive quick scan that generates a baseline assessment of the sustainability of UWCS in a municipality or other dominantly urban region. It covers

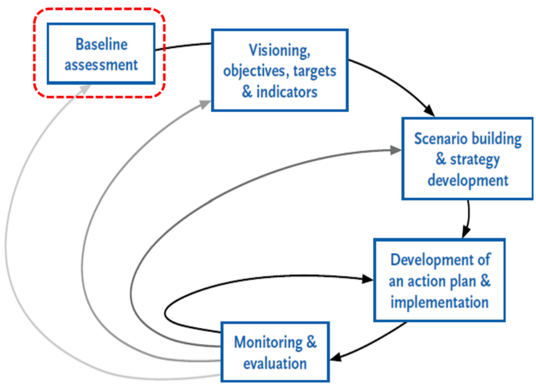

Fig. 1 Function of the City Blueprint (*red box*) in the strategic planning process for UWCS according to SWITCH (Philip et al. 2011)

24 key indicators divided over eight broad categories: water security, water quality, drinking water, sanitation, infrastructure, climate robustness, biodiversity and attractiveness as well as governance (Table 1; Van Leeuwen 2013). The indicators are scored on a scale between 0 (very poor performance) to 10 (excellent performance). Data gathering was standardized by means of a questionnaire with 24 questions in five headings: (1) general information, (2) drinking water, (3) waste water, (4) environmental quality, biodiversity and attractiveness and (5) governance (Van Leeuwen and Marques 2013; European Commission 2015). A short summary of the methodology is provided in Table 1. In order to provide full transparency about the indicators, the data sources, the scoring methodology and sample calculations for each of the 24 indicators are provided in a City Blueprint Questionnaire which can be downloaded from the Web site of the European Innovation Partnership on Water (European Commission 2015). The collection of information for cities has been carried out by the authors and/or by several stakeholders (representatives of municipalities, water utilities, wastewater utilities and water boards) on the preliminary assessment. Final reporting was done in an interactive manner with the stakeholders.

The overall score of the sustainability of UWCS of the city is expressed as Blue City Index (BCI). The BCI is the arithmetic mean of the 24 indicators comprising the City Blueprint and has a theoretical minimum and maximum of 0 and 10, respectively (Table 1). The City Blueprint method, including the BCI, also has some serious shortcomings. This holds for quality of the data sources, as well as for the scaling and aggregation method. A major revision of the City Blueprint assessment framework will take place in the Horizon 2020 project BlueSCities (European Commission 2015), with the aim to include solid waste. The review is also carried out to provide a better separation between the local UWCS management performance in cities and the 'context' of cities, i.e., the social, environmental and financial trends and pressures in countries. A critical evaluation of the method is provided by Van Leeuwen and Sjerps (2015b).

Table 1 Short summary of the City Blueprint method

Goal	Baseline assessment of the sustainability of UWCS
Indicators	Twenty-four indicators divided over eight broad categories 1. Water security 2. Water quality 3. Drinking water 4. Sanitation 5. Infrastructure 6. Climate robustness 7. Biodiversity and attractiveness 8. Governance
Data	Public data or data provided by the (waste) water utilities and cities based on a questionnaire (European Commission 2015)
Scores	0 (concern) to 10 (no concern)
BCI	Blue City Index®, the arithmetic mean of 24 indicators which varies from 0 to 10
Stakeholders	Water utility, water board, city council, companies, NGOs, etc.
Process	Interactive with all stakeholders involved early on in the process

The City Blueprint analyses for the 45 municipalities and regions have been carried out as described before (Van Leeuwen 2013), except for the indicator nutrient recovery. In some countries, for instance in the Netherlands, it is forbidden by law to recycle sewage sludge in agriculture as sludge is often contaminated with heavy metals, pharmaceutical residues and metabolites or other persistent toxic chemicals. Often sludge is incinerated without nutrient recovery. In some cities, however, specific new nutrient recycling facilities are installed to treat wastewater, e.g., for the production of struvite ($MgNH_4$-$PO4{\cdot}6H_2O$). Struvite is then used as fertilizer in parks or sport fields (Van Leeuwen and Sjerps 2015a). Thus, nutrient recycling takes place if (1) nutrients are extracted from wastewater, either directly (struvite production) or (2) indirectly by the application of sewage sludge in agriculture.

3 Cities and regions

City Blueprints are available for the following 45 municipalities and regions in 27 different countries, mainly in Europe (Fig. 2): Algarve (Portugal), Amsterdam (the Netherlands), Ankara (Turkey), Athens (Greece), Belém (Brazil), Berlin (Germany), Bologna (Italy), Bucharest (Romania), Budapest (Hungary), Copenhagen (Denmark), Dar es Salaam (Tanzania), Dordrecht (the Netherlands), Eindhoven (the Netherlands), Eslov (Sweden), Galati (Romania), Genova (Italy), Hamburg (Germany), Helsingborg (Sweden), Helsinki (Finland), Ho Chi Minh City (Vietnam), Istanbul (Turkey), Jerusalem (Israel), Kilamba Kiaxi (Angola), Kristianstad (Sweden); Ljubljana (Slovenia), Lodz (Poland), London (UK), Lyon (France), Maastricht (the Netherlands), Malmö (Sweden), Malta (Malta), Manresa (Spain), Melbourne (Australia), New York (USA), Nieuwegein (the Netherlands), Oslo (Norway), Reggio Emilia (Italy), Reykjavic (Iceland), Rotterdam (the Netherlands), Scotland (UK), Stockholm (Sweden), Varna (Bulgaria), Venlo (the Netherlands), Wroclaw (Poland) and Zaragoza (Spain).

Fig. 2 Geographical distribution of the 45 municipalities and regions assessed in this study

4 Results

Cities vary considerably with regard to the sustainability of the UWCS. This is captured in the Blue City Index® (BCI), the arithmetic mean of 24 indicators comprising the City Blueprint which varies theoretically from 0 to 10. In 45 cities and regions assessed so far, the BCI varied from 3.5 to 8.5. Cities with BCI values of 7.5 or greater are as follows: Amsterdam (Van Leeuwen and Sjerps 2015a), Berlin, Dordrecht, Hamburg (Van Leeuwen and Bertram 2013), Helsingborg, Helsinki, (Fig. 3), Jerusalem, Kristianstad, Malmö, New York and Stockholm (Table 2). Cities with BCIs lower than five are as follows: Belém, Dar es Salaam, Kilamba Kiaxi and Malta (Fig. 3).

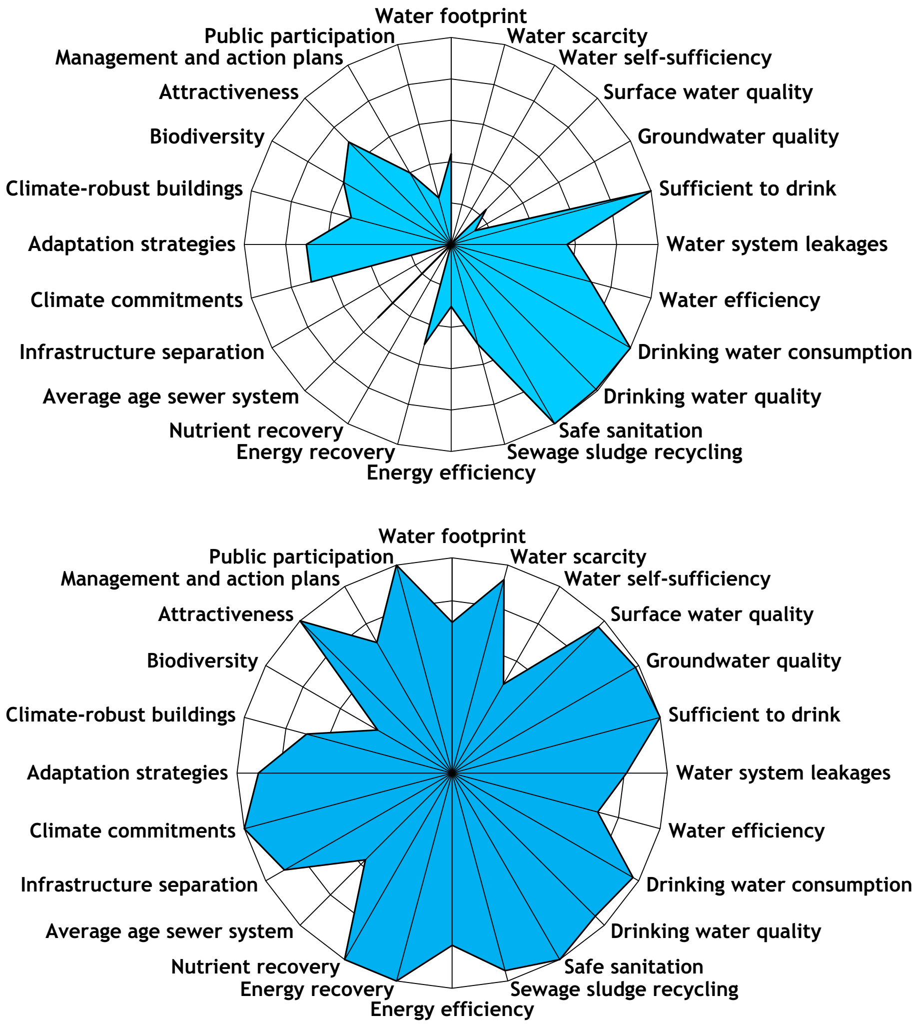

Fig. 3 City Blueprint of Malta (*top*) and Helsingborg (*bottom*), based on 24 indicator scores. The range of the scores varies from 0 (centre of the circle) to 10 (periphery of the circle). The Blue City Index (BCI) of Malta and Helsingborg are 4.9 and 8.5, respectively. Further details are provided in the text and in the City Blueprint Questionnaire (European Commission 2015)

Table 2 Summary information about the BCI, UWCS management and action plans (indicator 23) for cities/regions, VPI and various national indexes from the IMF (2014) and World Bank (2013). Abbreviations: see text

	BCI	UWCS	VPI	GE	RQ	RL	GDP ($) 2014	ND-GAIN Readiness	ND-GAIN Vulnerability	ND-GAIN Index
Algarve	6.1	6	1.0	86	76	83	20,892	0.674	0.314	68
Amsterdam	8.0	7	7.7	97	97	97	48,783	0.784	0.317	73
Ankara	6.0	5	0.5	66	65	56	11,499	0.541	0.305	62
Athens	6.4	5	1.3	67	73	64	21,562	0.589	0.297	65
Bélem	3.6	0	0.3	51	55	52	13,027	0.411	0.274	57
Berlin	7.8	10	3.3	91	93	92	44,870	0.819	0.242	79
Bologna	6.3	7	1.7	67	75	62	34,291	0.632	0.274	68
Bucharest	5.2	6	0.7	53	69	56	9087	0.562	0.374	59
Budapest	6.9	6	1.0	70	78	67	13,966	0.636	0.309	66
Copenhagen	7.0	8	8.3	99	98	99	59,166	0.872	0.243	81
Dar es Salaam	4.1	2	0.3	29	41	39	713	0.370	0.493	44
Dordrecht	7.5	7	7.7	97	97	97	48,783	0.784	0.317	73
Eindhoven	6.4	7	7.7	97	97	97	48,783	0.784	0.317	73
Eslöv	7.4	4	10	99	99	100	62,452	0.869	0.238	82
Galati	5.5	7	0.7	53	69	56	9087	0.562	0.374	59
Genova	5.7	3	1.7	67	75	62	34,291	0.632	0.274	68
Hamburg	7.6	10	3.3	91	93	92	44,870	0.819	0.242	79
Helsingborg	8.5	7	10	99	99	100	62,452	0.869	0.238	82
Helsinki	7.9	8	5.3	100	99	99	49,862	0.867	0.237	82
Ho Chi Minh City	5.4	7	0.3	44	28	39	1844	0.437	0.415	51
Istanbul	5.3	5	0.5	66	65	56	11,499	0.541	0.305	62
Jerusalem	7.6	10	1.7	85	86	80	33,373	0.665	0.325	67
Kilamba Kiaxi	3.5	2	0.2	29	15	9	6292	0.292	0.490	40
Kristianstad	8.0	6	10	99	99	100	62,452	0.869	0.238	82
Ljubljana	7.0	7	3.3	79	72	81	23,020	0.739	0.264	74
Lodz	6.7	4	1.0	71	81	73	13,728	0.677	0.272	70
London	7.1	10	3.3	90	96	93	38,958	0.803	0.203	80
Lyon	7.2	7	3.0	89	85	88	43,582	0.748	0.235	76
Maastricht	6.9	8	7.7	97	97	97	48,783	0.784	0.317	73
Malmö	8.0	6	10	99	99	100	62,452	0.869	0.238	82
Malta	4.9	4	2.3	87	87	87	22,965	0.592	0.360	62
Manresa	6.6	6	1.7	83	79	81	30,515	0.650	0.251	70
Melbourne	7.0	10	8.3	95	97	96	69,674	0.789	0.187	80
New York	7.5	10	5.0	91	87	91	53,328	0.799	0.221	79
Nieuwegein	6.3	8	7.7	97	97	97	48,783	0.784	0.317	73
Oslo	7.4	7	10	98	95	100	106,134	0.858	0.204	83
Reggio Emilia	6.6	6	1.7	67	75	62	34,291	0.632	0.274	68
Reykjavik	7.0	8	10	90	82	92	46,323	0.799	0.223	79
Rotterdam	7.0	8	7.7	97	97	97	48,783	0.784	0.317	73
Scotland	6.6	6	3.3	90	96	93	38,958	0.803	0.203	80

Table 2 continued

	BCI	UWCS	VPI	GE	RQ	RL	GDP ($) 2014	ND-GAIN Readiness	ND-GAIN Vulnerability	ND-GAIN Index
Stockholm	7.7	8	10	99	99	100	62,452	0.869	0.238	82
Varna	5.3	5	0.7	53	68	51	7881	0.589	0.303	64
Venlo	6.2	8	7.7	97	97	97	48,783	0.784	0.317	73
Wroclaw	6.1	4	1.0	71	81	73	13,728	0.677	0.272	70
Zaragoza	6.6	7	1.7	83	79	81	30,515	0.650	0.251	70

The BCI (calculated on the basis of 23 indicators, i.e., excluding indicator 23 to provide full independency of the data) was positively correlated with the UWCS management and action plans (indicator 23). The relation is shown in Fig. 4. The BCI (calculated on the basis of 23 indicators, i.e., excluding indicator 24 to provide full independency of the data) was also positively correlated with the voluntary participation index (VPI; indicator 24). Furthermore, positive correlations were shown for the BCI and the governance indicators according to the World Bank (Table 3), such as government effectiveness (GE; Fig. 5), regulatory quality (RQ) and rule of law (RL). The same positive correlation (Table 3) was demonstrated for the gross domestic product (GDP) per person, for which we took the GDP per capita, current prices in US dollars for 2014 (IMF 2014). We also calculated the Pearson correlation coefficient between the BCI and the University of Notre Dame Global Adaptation Index (ND-Gain 2014). This index measures the vulnerability of each nation in the world to climate change and its readiness to adapt (ND-Gain 2013). Readiness targets those portions of the economy, governance and society that affect the speed and efficiency of absorption and implementation of adaptation projects. The results are summarized in Tables 2 and 3. The relation between the ND-GAIN Index and the BCI is given in Fig. 6. Although correlation coefficients are no cause–effect relations, cities with the best BCI are cities:

- With an active civil society expressed as VPI ($r = 0.56$; $n = 45$; $p = 0.000063$)
- With high UWCS commitments ($r = 0.62$; $n = 45$; $p = 0.000001$; Fig. 4)
- In countries with a high GDP ($r = 0.72$; $n = 45$; $p < 0.0000001$)
- In counties with a high government effectiveness ($r = 0.83$; $n = 45$; $p < 0.0000001$; Fig. 5)
- In nations with a high global adaptation index (ND-GAIN; $r = 0.87$; $n = 45$; $p < 0.0000001$; Fig. 6), and especially in countries with a high readiness to adapt to climate change (Table 3).

These results are very promising as they show that the water challenges can be solved by ambitious leaders and an active civil society in municipalities and regions (Fig. 4). It does also require effective government (Fig. 5), effective water governance (OECD 2011) and adequate funding (a high GDP—Tables 2, 3) for the high costs of water infrastructure. These aspects were also highlighted in a recent report on water in cities by the OECD (2015). It can be concluded that cities need to start investing in adaptation and mitigation measures based on a long-term vision and strategy and by sharing best practices. Although we have only assessed a limited number of cities outside Europe, our results show that cities in transitional and developing countries are particularly at risk as their current

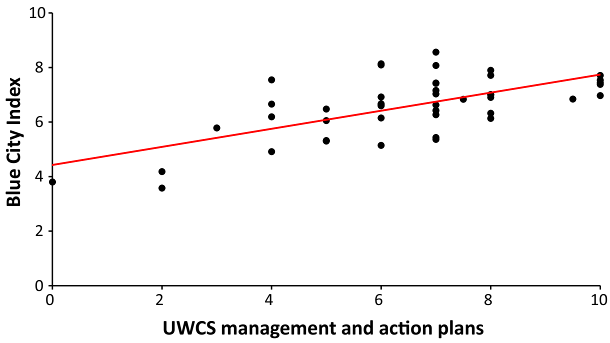

Fig. 4 Relation between the BCI and UWCS management and action plans (indicator 23) for 45 cities and regions. The calculations for the BCI have been performed for 23 indicators, i.e., leaving out indicator 23 (UWCS management and action plans) in order to provide full independency of the data. The Pearson correlation coefficient is 0.62 ($n = 45$)

Table 3 Pearson correlation matrix for the indicators of 45 cities and/or regions (n = 45) in 27 different countries. Abbreviations: see text

	BCI	UWCS	VPI	GE	RQ	RL	GDP-IMF	ND-GAIN Readiness	ND-GAIN Vulnerability	ND-GAIN Index
BCI	1.00	0.62	0.56	0.83	0.80	0.82	0.72	0.89	−0.68	0.87
UWCS		1.00	0.35	0.58	0.54	0.57	0.47	0.60	−0.41	0.57
VPI			1.00	0.79	0.72	0.79	0.88	0.81	−0.45	0.73
GE				1.00	0.94	0.98	0.83	0.94	−0.70	0.92
RQ					1.00	0.95	0.77	0.93	−0.71	0.91
RL						1.00	0.82	0.95	−0.69	0.92
GDP-IMF							1.00	0.84	−0.65	0.83
ND-GAIN Readiness								1.00	−0.75	0.98
ND-GAIN Vulnerability									1.00	−0.88
ND-GAIN Index										1.00

Correlations of the BCI with UWCS and Voluntary Participation Index (VPI) are calculated using an adjusted BCI of 23 indicators that respectively leaves out the UWCS and VPI in order assure full independency of the data

performance on UWCS needs improvement and the trends and pressures in these countries are high (Tables 2, 3; Dobbs et al. 2011, 2012; World Bank 2013; Van Leeuwen 2013).

5 Discussion

5.1 Methodological aspects

A critical evaluation of the City Blueprint method is provided by Van Leeuwen and Sjerps (2015b). The main problem to review urban water management is the lack of high-quality

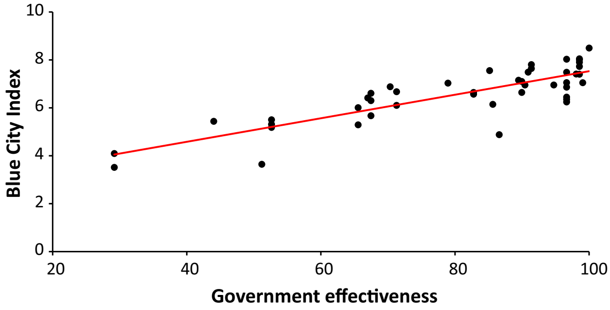

Fig. 5 Relation between the BCI and government effectiveness (World Bank 2013) for 45 cities and regions. The Pearson correlation coefficient is 0.83 ($n = 45$)

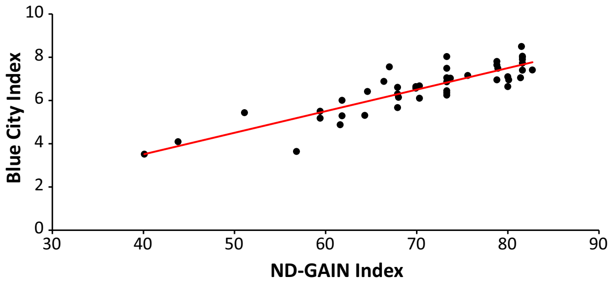

Fig. 6 Relation between the BCI and ND-GAIN Index (ND-Gain 2013) for 45 cities and regions. The Pearson correlation coefficient is 0.87 ($n = 45$)

information at the local level. Therefore, national data have been used for the following indicators: water footprint, water scarcity, water self-sufficiency, surface water quality and groundwater quality, biodiversity and public participation. The use of national data on environmental quality may lead to serious overestimations of local environmental quality as cities are often sources of pollution (Grimm et al. 2008; Bai 2007). In other words, the scores as provided in the current paper on environmental quality are probably too optimistic and are serious underestimations of the actual environmental quality of cities. Furthermore, many other water pollutants have not been accounted for.

5.2 Water supply

This paper provides a general overview of our research on 45 municipalities and regions with a selection bias toward Europe (Fig. 2). Detailed assessments have been published for the cities Rotterdam (Van Leeuwen et al. 2012), Dar es Salaam (Van Leeuwen and Chandy 2013), Hamburg (Van Leeuwen and Bertram 2013), Amsterdam (Van Leeuwen and Sjerps 2015a), Istanbul (Van Leeuwen and Sjerps 2015b) and Ho Chi Minh City (Van Leeuwen et al. 2015). Another detailed assessment of Melbourne that highlights the reaction to the impact of the millennium drought has recently been submitted.

The City Blueprints can be used for priority setting and are a good starting point for discussions about the transition toward sustainable and resilient UWCS (Fig. 1). Relevant aspects to consider are urban water governance and the emerging pressures affecting water security and safety (OECD 2011, 2015). Water infrastructure which underlies urban water security is generally aging and often requires a lot of maintenance (OECD 2015). As the City Blueprint is a static assessment (a snapshot) of UWCS in a city, more in-depth assessments and dynamic modeling are needed as a follow-up to develop a roadmap for the transition process (Fig. 1; OECD 2015). The various options for arriving at sustainable UWCS come at a price. Savings can be achieved by focusing on thinking in terms of longer-term investment rather than short-term expenditure and by smarter integration by searching for win–win's or co-benefits. For example, water-wise or 'smarter' cities are cities that take advantage of these (long-term) win–win opportunities by are water-wise cities that integrate integrating water, waste water, energy, solid waste, transport, ICT, housing, climate adaptation, nature (blue–green infrastructure) and governance (people). Besides substantial opportunities for financial savings, the long-term integrative approach of smarter cities may result in attractive cities for citizens and business investments. This transition to 'smarter' cities requires a long-term coherent plan (Van Leeuwen et al. 2012; European Commission 2015).

The main drivers behind the expansion of water-related developments are population growth and increased per capita demand, the increase in irrigated agriculture and industrial development (Cashman and Ashley 2008; Van Leeuwen 2013; OECD 2015). The efficiency with which water is used has become a major consideration, especially in urban supply as the scale of losses is relevant. A significant percentage of distributed water never reaches the final user but is lost due to leakage. For the 45 cities and regions, the average leakage rate was 21 %, with a lowest and highest value of 2 % (Berlin) and 60 % (Varna), respectively. In many cities, water efficiency can still be improved although the average score for water efficiency was 7.9 on a scale from 0 to 10.

The challenges for securing water supply have been observed in many cities and regions, e.g., Malta (Fig. 3), Istanbul (Van Leeuwen and Sjerps 2015b), Dar es Salaam (Van Leeuwen and Chandy 2013), Ho Chi Minh City and Athens. Even for a city like Oslo in Norway, one of the countries with very high water resources (FAO 2015), future urbanization may necessitate further actions to either reduce water consumption or to increase water supply (Van Leeuwen 2013). In many major cities in the developing world, piped water supplies are intermittent and, often, do not meet accepted quality guidelines (UN 2014). This has also been observed for several cities with very low BCIs (Table 2). It becomes increasingly important for water-scarce cities to make more efficient use of available water by decreasing leakages from urban water systems, increasing the use of recycled water (water reuse) and improving water efficiency (Grant et al. 2012; Van Leeuwen 2013; McDonald et al. 2014). Coastal cities in water-scarce regions may also turn to desalination, although it remains a relatively expensive solution.

5.3 Climate change and water security

Despite mitigation efforts to reduce greenhouse gas emissions, climate change is already being witnessed. The 2001–2010 decade was the warmest since modern temperature monitoring began around 160 years ago (WMO 2013). Climate change may increase the occurrence and intensity of extreme events such as long periods of drought, severe storms and extreme precipitation (WMO 2013; EEA 2012). In our assessment of the city of Melbourne, it appeared that the overall commitments to adaptive, multifunctional, infrastructure and design for UWCS were high. The challenges of managing urban water systems under a changing and uncertain climate became starkly apparent during Australia's 'Millennium Drought,' a decade-long period of extremely dry conditions throughout the 2000s (Chong 2014). In Melbourne, a transparent governance structure has been set up in a reaction to this Millennium Drought and success has come from many organizations working together to a common goal. Melbourne scored high in areas such as water efficiency, wastewater efficiency, i.e., energy recovery, and climate change commitments related to heat and water scarcity. Nearly 30 % of the houses in Melbourne have installed rainwater tanks and plans to increase the use of stormwater have recently been published. Similar challenges remain on the agenda for Mediterranean and Central and Eastern European cities. For instance, Istanbul faces water scarcity from rapid urbanization and as a result of climate change (EEA 2012; Van Leeuwen and Sjerps 2015b). In fact, climate change will affect many cities in areas where the blue water footprint exceeds the blue water availability (Hoekstra et al. 2012; EEA 2012; FAO 2015) or where groundwater supplies are diminishing as an estimated 20 % of the world's aquifers are overexploited (UN 2014).

Particularly, at risk are cities in transitional and developing countries, where the trends and pressures of urbanization and economic growth (UN 2012; Dobbs et al. 2011, 2012; Van Leeuwen 2013) and climate change (Hoekstra et al. 2012; Hoekstra and Wiedman 2014; World Economic Forum 2014), a lack of awareness and readiness (Tables 2, 3; Fig. 6), or the lack of ambition (Fig. 4), and limited government effectiveness (Fig. 5) together with limited financial resources for infrastructure construction and maintenance (Sect. 5.5) are immense challenges.

5.4 Climate change and floods

Floods are the most prevalent natural hazard in Europe. In a recent analysis, it was estimated that EU floods cost €4.9 billion a year on average from 2000 to 2012, a figure that could increase to €23.5 billion by 2050 (Jongman et al. 2014). In addition, large events such as the 2013 floods in Europe are likely to increase in frequency from an average of once every 16 years to a probability of every 10 years by 2050 (Jongman et al. 2014). A well-known example is the City of Copenhagen. As a result of a huge thunderstorm during a period of 2 h 150 mm of rain fell in the city center on July 2, 2011. Sewers were unable to handle this amount of water, and many streets were flooded and sewers overflowed into houses, basements and onto streets, thereby flooding the city. The first estimate of the damage was €700 million (EEA 2012), but a more in-depth review showed that the damage was actually nearly €1 billion (Leonardsen 2012). Similar observations can be made for the USA, for example in the case of Hurricane Katrina in 2005. It was one of the deadliest hurricanes ever to hit the USA. An estimated 1836 people died. Total property damage from Katrina was estimated at US $81 billion, which was nearly triple the damage inflicted by Hurricane Andrew in 1992 (Zimmerman 2012). The third example is Hurricane Sandy that hit New York in 2012. The city was severely affected, particularly New York City, its suburbs, and Long Island. Sandy's impacts included the flooding of the New York City subway system, many suburban communities and many road tunnels entering Manhattan. Sandy damaged 200,000 homes and was blamed for 117 US deaths. The total damage in New York was estimated at more than $19 billion (Toro 2013). Pollution and social stress are more difficult to quantify financially, but in general, it can be assumed that the real costs of flooding in cities are seriously underestimated.

Stormwater retention and stormwater separation are key urban adaptation measures. Some cities such as New York, Copenhagen, Amsterdam and Rotterdam are taking action to increase the retention (e.g., by green space such as swales or green roofs or by water squares) or to rapidly increase the discharge of excess water to less vulnerable areas to minimize damage. From the 45 City Blueprints that have been made, it can be concluded that many cities and regions still have combined sewers. For those water bodies that do not yet meet water quality standards for pathogens, the biggest remaining challenge is to further reduce combined sewer overflows that discharge a mixture of untreated sewage and stormwater runoff when it rains (NYC 2010; EEA 2012). Only a few cities have completely separated stormwater sewers from the sanitary sewers. In fact, the average infrastructure separation for all cities and regions studied is <50 %. It implies that existing water infrastructure needs reengineering to sustain a high standard of living while reducing its environmental footprint and sustaining or restoring biodiversity (Grant et al. 2012). Therefore, proper asset management for water and waste water infrastructure is and should remain a major task for all cities.

5.5 The cost of urban water infrastructure

The water sector faces severe challenges in meeting the financial requirements for maintaining, extending and upgrading new and aging water systems in the face of growing water scarcity, stricter regulatory requirements and competition for capital (Cashman and Ashley 2008). Extreme weather events such as floods, as discussed above, may have devastating effects too and will further increase these costs. The cost of urban infrastructure is staggering. The UNEP (2013) estimates that for the period 2005–2030 about US$ 41 trillion (trillion = 10^{12}) will be required to refurbish the old (in mainly developed country cities) and build new (mainly in the developing country cities) urban infrastructures, where the cost of the water infrastructure (US$22.6 trillion) has been estimated at more than that for energy, roads, rail, air and seaports put together. The wastewater infrastructure is responsible for the largest share of these 22.6 trillion. We have used the average age of the sewer system as a very rough indicator for maintenance. It would have been better to use the quotient of the actual average age and the local maximum age, but these data are hardly available. From our study, it appears that the actual average age of the sewer system is approximately 40 years, whereas the separation of storm water and sanitary sewers is approximately 50 %. This implies that for most cities combined sewers will continue to cause significant surface water pollution as a result of sewer overflows in case of extreme rain events. At the same time, it is an extra handicap for those cities who want to increase their water productivity by improving on substitution (substituting higher-quality water with lower-quality water) and regeneration (regenerating higher-quality water from lower-quality water by treatment) as discussed by Grant et al. (2012).

6 Conclusions

The goal of this study was to review water management in 45 municipalities and regions, with a focus on Europe. An important result from this study is that the variability in sustainability of UWCS among cities offers great opportunities for short-term and long-term improvements, provided that cities share their best practices. This is the ultimate goal of our EIP Water Action Group (Van Leeuwen 2013; European Commission 2015). It is concluded that:

- Cities are the major problem holders. Active civil societies including the private sector with visionary local government can cope with water challenges. Water governance is the main challenge.
- The local urban level is the relevant scale for water governance. It requires a multi-level water governance approach, a long-term strategy, a bottom-up approach and

collaboration among cities and regions by sharing best practices for rapid implementation (Philip et al. 2011; OECD 2011, 2015).

- Particularly at risk are cities in transitional and developing countries, where the trends and pressures of urbanization, economic growth and climate change, a lack of awareness and readiness, or the lack of ambition and government effectiveness, or limited financial resources for infrastructure construction and maintenance are immense challenges (Tables 2, 3; Figs. 4, 5 and 6).
- The longer political leaders wait, the more expensive adaptation will become and the danger to citizens and the economy will increase (EEA 2012).
- The time window to do this is narrow and rapidly closing (Water Resources Group 2009; UN 2014; European Commission 2015).

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