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Assessment of the Sustainability of Water Resources Management: A Critical Review of the City Blueprint Approach

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Abstract Climate change, urbanization and water pollution cause adverse effects and rehabilitation costs that may exceed the carrying capacity of cities. Currently, there is no internationally standardized indicator framework for urban Integrated Water Resources Management (IWRM). The City Blueprint® is a first attempt and aims to enhance the transition towards water-wise cities by city-to-city learning. This paper provides a three step revision of the City Blueprint Framework (CBF) based on data of 45 municipalities and regions in 27 countries: (1) A distinction has been made between *trends and pressures* (on which urban IWRM has a negligible influence) and *IWRM performances*. Therefore, a separate trends and pressures framework has been developed; (2) Only the purely performance-oriented indicators have been selected from the CBF. Furthermore, the indicator accuracy and boundaries have been re-assessed, and new indicators have been added; (3) By analyzing correlations and variances, the performance-oriented indicators have been rearranged in order to establish a proportional contribution of all indicators and categories to the overall score, i.e., the Blue City Index®. In conclusion, six indicators have been removed because of insufficient accuracy, overlap or lack of focus on IWRM. Seven indicators have been added, i.e., secondary and tertiary wastewater treatment, operation cost recovery, green space and three indicators concerning solid waste treatment. The geometric aggregation method has been selected because it emphasizes the need to improve the lowest scoring indicators. In conclusion, the improved CBF is more performance-oriented and therefore more suitable to assist cities in their transition towards water-wise cities.

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1 Urban Water Challenges

Rapid urbanization and climate change pose increasing pressures on Integrated Water Resources Management (IWRM), especially in cities (OECD 2015). In 2014, about 4 billion people lived in cities, mostly situated along coasts and major rivers (accounting for 54 % of the world's population). IWRM becomes even more challenging as the global urban population is estimated to increase with 2.5 billion people by 2050 (UN 2014).

Climate change amplifies urban water vulnerabilities such as flooding, heat stress, water scarcity and water pollution. Sea level rise and increased river discharges pose a projected 15 % of the global population at risk of flooding. This is mainly in cities including almost all worlds' megacities (Ligtvoet et al. 2014). Also, extreme rainfall and heat waves will become more severe due to global warming (Jongman et al. 2014). As urban surfaces are often largely sealed and lack green areas, the impact of drainage flooding and Urban Heat Islands (UHI) are even more exacerbated (Shuster et al. 2005; Gill et al. 2007). Water withdrawals are estimated to increase by 50 % in developing countries and by 18 % in developed countries by 2025 (WWDR 2006). This increased water demand will lead to an estimated 40 % fresh water shortage by 2030 (2030 WRG 2009). Climate change will exacerbate these fresh water shortages (Iglesias et al. 2007) and amplify the spread of water-borne diseases (IPCC 2013). Pollution from combined sewer overflows and stormwater runoff will rise due to climate induced increase in extreme rainfall events (Nilsen et al. 2011). Rapid urbanization poses extra stresses, for example, wastewater treatment in Asia and Africa is already sparse, while nutrient emissions are projected to double or triple within 40 years. This will strongly enhance eutrophication, biodiversity loss, threaten drinking water, fisheries, aquaculture, and tourism (Ligtvoet et al. 2014). Moreover, cities produce massive amounts of solid waste, in particular plastics. Worldwide 280 million tons of plastics are produced annually (Sigler 2014). These plastics photodegrade into small particles that affect marine ecosystems (Derraik 2002).

The prospect of increased urban flooding, heat stress, water scarcity and pollution emphasizes the need for adaptive and reliable urban water infrastructures (Short et al. 2012). However, water infrastructures are often old and require refurbishment to meet current standards, whereas standards to withstand future conditions of increased storm events and urbanization are often not accounted for (OECD 2015). An estimated US$ 41 trillion (41×10^{12}) is needed to refurbish the urban infrastructure in the period 2005–2030. Over 50 % will be needed to refurbish the water systems (UNEP 2013). This is roughly 60 % more than is spent on infrastructure in the same period until now (McKinsey 2013). In developed countries water infrastructure investments amount to 1 % of the GDP every year. For developing countries this is even more substantial, i.e., about 3.5 % with extremes up to 6 % or more (Cashman and Ashley 2008). The costs of climate change related damages are expected to be large. In Europe this is estimated to be € 190 billion by 2080 (JRC 2014), especially flood

damage is predicted to increase five-fold by 2050 (Jongman et al. 2014). Recent extreme weather events resulted in much damage. For example, in 2011 in Copenhagen a storm event caused a lot of damage of nearly € 1 billion (Leonardsen 2012). In the USA, hurricane Sandy (2012) caused 117 deaths and costs US$ 19 billion including US$ 2.6 billion to repair New York's drinking and wastewater infrastructure (Johnson 2013). These alarming events demonstrate the climate vulnerability of cities and the urgency to improve urban IWRM.

2 The City Blueprint

Approximately 80 % of the world's GDP is produced, and 75 % of the global energy and material flows are consumed in cities (UNEP 2013). This makes cities the major contributors of economic growth but also the major sources of environmental pressures. It also implies that cities have the highest potential to reduce these pressures. Urban water management is often locked-in to the large-scale, centralized infrastructure approaches limiting the adoption of more flexible and resilient technologies and approaches such as fit-for-purpose water use, nutrient and energy recovery from wastewater, and blue-green infrastructures (Brown et al. 2011). Hence, the main objective of the City Blueprint® action is to create awareness among decision makers and resource managers. It may help them envisioning, developing and implementing stepwise measures to transform towards water-wise or water sensitive cities (EC 2015). Improving the implementation capacities of cities by sharing information can be described as city–to-city learning. The first step in the strategic planning process is that stakeholders are identified and information is provided for a baseline assessment. Hereafter, long-term goals and priorities are set resulting in follow-up actions leading to measures that promote sustainable IWRM (Philip et al. 2011; Van Leeuwen and Sjerps 2015). The City Blueprint Framework (CBF) aims to be the first step in strategic planning and consists of 24 indicators divided over eight broad categories, i.e., 1) Water security, 2) Water quality, 3) Drinking water, 4) Sanitation, 5) Infrastructure, 6) Climate robustness, 7) Biodiversity and attractiveness, and 8) Governance. The output is a spider diagram and a Blue City Index® (BCI). The BCI is the arithmetic mean of the 24 indicators. The methodology and its application have been published in this journal (Van Leeuwen et al. 2012; Van Leeuwen 2013) and a detailed description of the calculation methods is provided in the City Blueprint questionnaire available on the website of the European Innovation Partnership on Water (EC 2015).
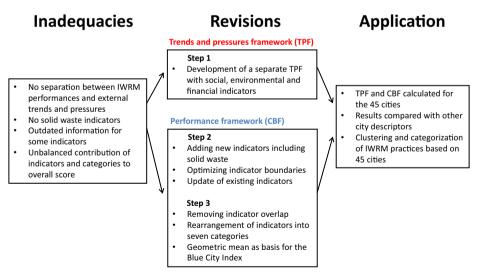
This paper provides a critical revision of the CBF, based on the learning experiences obtained during the assessments in 45 cities in 27 countries. The aim of this revision is to:

• Provide a clear separation between indicators describing urban *trends and pressures* (on which local water managers have a negligible influence, e.g., current climatic conditions, demographic chances etc.) and indicators measuring *IWRM performance* in cities. The improved performance framework (CBF) will be more adequate in showing the potential

for improvements and enhances city-to-city learning because emphasizes the city's own IWRM performance.

- Develop a separate framework describing the most important trends and pressures that may limit IWRM or, on the contrary, poses opportunity windows. This supplementary framework is key in providing context and may assist in the setting of priorities.
- Include solid waste indicators as important urban performers to decrease water pollution.
- Update existing indicators by including new developments in data accuracy and availability.
- Design a coherent framework in which indicators and categories make a balanced contribution to the overall score, i.e., the BCI.
- Select an aggregation method that penalizes unbalanced indicator scores in order to express the urgency to improve the lowest scoring indicators.
- Make sure that the indicator results are easy to understand, timely and relevant, and useful for the end-users, i.e., policy makers, decision makers, water managers and citizens in general.

3 Methodology

The application of the CBF followed a learning by doing approach. Based on constructive feedback from stakeholders, we have performed a detailed revision of the indicator choice and framework, together with a revision of the indicator scaling and aggregation method (Koop and Van Leeuwen 2015b). The process is summarized in Fig. 1 and is based on data of 45

Fig. 1 Flow chart of the City Blueprint revision described in this paper using data of 45 cities divided over 27 countries. The applications of the Trends and Pressure Framework (TPF) and Performance framework (CBF) have been published in this journal (Koop and Van Leeuwen 2015a)

municipalities and regions, mainly in Europe (Koop and Van Leeuwen 2015a). In the rest of this paper these municipalities, regions and Malta will be referred to as cities. This review consists of three consecutive steps:

Step 1   Development of the Trends and Pressure Framework (TPF).
Step 2   Improvements of the City Blueprint indicators.
Step 3   Indicator rearrangements and aggregation methods.

The application of the revised CBF and new TPF, the clustering and categorization of cities' IWRM performances, as well as comparisons with other city descriptors, have been published separately in this journal (Koop and Van Leeuwen 2015a).

3.1 Step 1: Development of the Trends and Pressures Framework

Every city has its own social, financial and environmental setting in which water managers have to operate. In order to promote city-to-city learning, it is essential to solely measure urban water management performances. For example, a city situated in an arid area may not necessarily experience water stress due to overconsumption, but simply due to the low natural availability of fresh water. In this case, water consumption or the use of water saving techniques are performance indicators, whereas the natural availability of fresh water is a descriptive indicator belonging to the TPF. A more performance-oriented set of indicators (CBF) is more adequate in showing the potential for improvements and sharing of knowledge, experiences and best practices between cities. A separate TPF may provide the context to obtain insight in the limitations and windows of opportunities for urban IWRM. Therefore, the first step in this review was the development of the TPF with the aim to provide an overview of the most important social, environmental and financial characteristics affecting urban IWRM.

3.2 Step 2: Improvements of the City Blueprint Indicators

All indicators of the CBF have been critically assessed on data reliability, scoring method and whether the used data are time-series in order to ensure that the indicators are up-to-date. At the same time new indicators are proposed to replace indicators with data problems. Also boundary issues are reviewed in order to adjust extreme indicator variances. Alternative scaling methods for a few indicators with sufficiently large data sets ($n > 100$) are proposed as well. Only performance-oriented indicators have been selected in this step.

3.3 Step 3: Indicator Rearrangements and Aggregation Method

Finally, the revised performance-oriented indicators have been rearranged to arrive at a more coherent framework. The aim was to obtain intra-category correlations (correlations between indicators of the same category) that were higher than the inter-category correlations (correlations of the indicators belonging to different categories). Hence, high correlations between indicators suggest that these indicators should be united into

one category. Finally, it is aimed to equalize the number of indicators per category, to make sure that all categories equally contribute to the BCI. Furthermore, an aggregation method has been selected that penalizes unbalanced scores in order to emphasize the need to improve the lowest indicator scores.

4 Results

4.1 Step 1: Development of the Trends and Pressures Framework

Because the regenerative capacity and renewable resources on earth are limited (Hoekstra and Wiedman 2014), environmental pressures of cities need to be reduced provided that adequate living standards are maintained (Mori and Yamashita 2015). Hence, an equal number and weighing of indicators for social, environmental and financial classes has been strived for. Each indicator has been scaled from 0 to 4 points, where a higher score represents a higher urban pressure or concern. The following ordinal classes, expressed as 'degree of concern', have been used: 0–0.5 points (no concern), 0.5–1.5 (little concern), 1.5–2.5 (medium concern), 2.5–3.5 (concern), and 3.5–4 (great concern). In this way, a TPF is provided that depicts the most relevant topics that either hamper sustainable IWRM or, on the contrary, pose opportunity windows. Examples for three cities are shown in Section 4.4. For the social and financial categories, four well-known descriptive indicators have been selected, that are widely used to describe urban pressures. The environmental category is focussed on urban water and climate issues, i.e., flooding, water scarcity and heat risk (EEA 2012). Water quality is also included because cities are often situated at rivers and in deltas that receive pollution from upstream activities. Table 1 describes the scaling method and data sources of the indicators and sub-indicators that are proposed. Most of these indicators are scaled according to existing scaling methods. Furthermore, sub-indicator 5.4 (*Land subsidence*) and 6.3 (*Salinization and seawater intrusion*) are scaled according to an ordinal self-assessment.

   For seven indicators and sub-indicators we have proposed a scoring method as no international standards are available. The scores are determined using the ranking of the city amongst all available country scores (Fig. 2). The rankings are linearly standardized on a scale from 0 to 4 points (y-axis Fig. 2). Subsequently, an equation has been selected that best fits this ranking (lowest correlation coefficient: $r=0.97$; Table 1). Next, these equations are applied in order to determine the indicator scores for each city. The numbers are rounded and scores of 3 or 4 points are marked in red and communicated to the stakeholders because they are considered as a concern or great concern (see Table 3 in Section 4.4). These scores are not normative but only provide an indication of the urban pressures. Finally, the Trends and Pressure Index (TPI; the arithmetic mean of all twelve TPF indicators) can be calculated for each city.

4.2 Step 2: Improvements of the City Blueprint Indicators

4.2.1 The Use of Wastewater Treatment as Indicator for Surface Water Quality
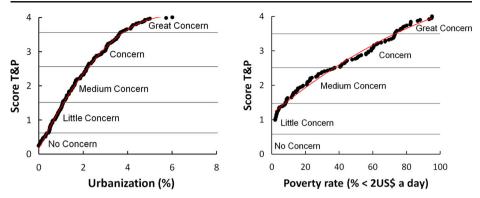
Baseline assessments of IWRM in cities should preferably include surface water quality and biodiversity. Unfortunately, this appears problematic as a result of a lack of local data and

Table 1 Summary of calculation methods for the indicators of the Trends and Pressures Framework developed in step 1 of this revision (Fig. 1). Three indicator categories are distinguished: (a) social indicators (nrs. 1–4), (b) environmental indicators (nrs. 5–8), and (c) financial indicators (nrs. 9–12). All indicators are categorized into five concern scores varying from 0 to 4, i.e., 0–0.5 points (no concern), 0.5–1.5 (little concern), 1.5–2.5 (medium concern), 2.5–3.5 (concern), and 3.5–4 (great concern). The equations are based on publicly available data and the derived relations are all significant (p max<10^{-6}), For a more detailed description of the data source and calculation method reference is made to the EIP City Blueprint website (EC 2015)

Indicator	Unit X	Method/Equation	Source
1. Urbanization rate	% per year	Score=$-0.114X^2+1.3275X+0.1611$ r=0.999	CIA 2014
2. Burden of disease	DALY's	Classification World Health Organization	WHO 2014
3. Education rate	% primary education	Score=$-10^{-5}X^3+0.0012X^2-0.0426X+4.3057$ r=0.974	World 2012
4. Political instability	World Bank standardized	Classification of the World Bank	World 2013a
5.1 Urban drainage flood	%flooded	Score=$6.10^{-8}X-2.10^{-5}X^{-4}+0.0014X^3-0.0526X^2+0.8302X-3.8745$ r=0.992	EEA 2015b
5.2. River peak discharges	% flooded	Classification of the EEA (2012)	EEA 2015b
5.3. Sea level rise	% flooded	Classification of the EEA (2012)	EEA 2015b
5.4. Land subsidence	Self-assessment	0=No infrastructure damage, no flood risk. 1=Low infrastructure damage expected, no increase in flood risk expected. 2=Infrastructure damage or <0.50 m subsidence. by 2100 in substantial urban area. 3=Serious infrastructural damage or <1 m subsidence substantial urban area by 2100. 4=As 3 with Imminent flood risk.	Case studies Local reports
6.1. Freshwater scarcity	% use of renewable resource	Classification of the OECD (2004) and WRI (2013)	FAO 2015
6.2. Groundwater scarcity	% use of renewable resource	Classification of the IGRAC (2010)	FAO 2015
6.3. Salinization and seawater intrusion	Self-assessment	0=Both not reported and city not vulnerable 1=Both not reported but city is vulnerable in the coming century and please use capitals in One/both 2=one/both not reported but imminent threat 3=one/both reported 4=one/both reported seriously affecting the city	Case studies Local reports
7.1. Surface water quality	WQI (Water Quality Index)	Score=[100 − WQI] / 25	EPI 2010

Table 1 (continued)

Indicator	Unit X	Method/Equation	Source
7.2. Biodiversity	% Water (effect on ecosystems) index	For EU: % water bodies less than good quality[a] For other: Score=100 − [Water (effects on ecosystems)/25]	EEA 2015a EPI 2010
8. Heat island effect		Average of the following two scores: (1) Number of hot days >35 °C and nights >20 °C[b] (2) Green space coverage (%)[c]	EEA 2015b EEA 2012
9. Economic pressure	GDP capita^{-1} day^{-1}	Score=-0.783 ln(X)+4.115 r=0.995	IMF 2013
10. Unemployment rate	%	Score=$0.0002X^2+0.5077X − 0.8356$ r=0.989 If <2 % score is 0 points and if x>20 score is 4	World 2014
11. Poverty rate	% <2US\$ day^{-1}	Score=$-0.0001X^2+0.0404X+1.1686$ r=0.994	World 2015
12. Inflation rate	% year^{-1}	Score=$0.0025X^3 − 0.0744X^2+0.866X+0.0389$ r=0.996	World 2013b

[a] The scores for the classification of water bodies (EEA 2015a) are as follows: 0–10 % (0), 10–30 % (1), 30–50 % (2), 50–70 % (3), >70 % (4)

[b] Annual number of hot days >35 °C and nights >20 °C standardized in a 0–4 range (boundaries: min. 0; max. 50)

[c] Green space coverage (%) standardized in a 0–4 range (boundaries have been set at the upper and lower 10 % of approximately 600 cities according to EEA (2012))

Fig. 2 Two examples of trends and pressure indicators developed in step 1 of this revision (Fig. 1). Left: urbanization rate (CIA 2014). Right: poverty rate (World Bank 2014). The urbanization and poverty rates of all available countries are ranked and subsequently linearly converted into scores of 0–4 (y-axis). Based on this score, ordinal classes, expressed as 'degree of concern', are used. Table 1 provides the calculation method

questionable data reliability. In the current CBF, the indicator *surface water quality* uses data from the water quality index (WQI) of the environmental performance index (EPI 2010). The WQI is the only global database of water quality for inland waters. However, insufficient spatial and temporal coverage of measurements, poor reporting and inconsistent sampling design, all posed data reliability problems (Srebotnjak et al. 2012). Therefore, the EPI stopped using the WQI after the year 2010 (EPI 2012).

A similar concern is the current indicator *biodiversity*, for which information is provided for member states of the European Union (EU), but this information is not available for non-EU countries (EEA 2014a). As an estimate for non-EU countries, the EPI water (effects on ecosystems) index has been used (EPI 2010). However, data reliability and the use of different databases appeared to be problematic (Emerson et al. 2010; Koop and Van Leeuwen 2015b). Moreover, both indices are national averages which lead to overestimations of urban water quality and biodiversity because cities are often large emitters of pollutants (Van Leeuwen 2013; Gessner et al. 2014).

Cities may have hardly any direct influence on the scores for surface water quality and biodiversity because of upstream pollution. Hence, the indicators *water quality* and *biodiversity* should focus on the city's own IWRM performance to prevent pollution. The coverage of secondary Waste Water Treatment (WWT) greatly determines the quality and biodiversity in urban waters because detrimental effects on aquatic species due to oxygen depletion are avoided. WWT removes at least 70 % of the biological and 75 % of the chemical oxygen demand (OECD 2013). Furthermore, the coverage of tertiary WWT avoids eutrophication by removing nitrogen and phosphorous, as well as other (microbiological) pollutants (OECD 2013). Secondary and tertiary WWT data are often available at the level of cities, frequently updated and widely used by international organizations (ISO 2014; UN Water 2014; OECD 2013; Siemens 2015; SOPAC 2004).

The scores for indicators 10 (*nutrient recovery*), 11 (*energy recovery*) and 12 (*sewage sludge recycling*) have been updated. These indicators reflect the reuse of wastewater as a fraction of the water that is passing the city's wastewater treatment plants; whereas the city's WWT service coverage is disregarded. Hence, a city that only treats a small fraction of its wastewater, but fully recycles the nutrients, sludge and applies full energy recovery from this small fraction, would receive a high score

for these indicators while loads of potentially abstractable nutrients, sludge and energy actually flush away. In order to take all urban wastewater into account, the scores are therefore multiplied by the fraction of wastewater (F) that is actually treated at the WWT facilities (Eqs. 1, 2 and 3).

$$\text{Score for nutrient recovery} = (\text{nutrient recovery}(\%) * F)/10 \qquad (1)$$

$$\text{Score for energy recovery} = (\text{energy recovery}(\%) * F)/10 \qquad (2)$$

$$\text{Score for sewage sludge recycling} = (\text{sewage sludge recycling} (\%) * F)/10 \qquad (3)$$

4.2.2 Public Participation

The Voluntary Participation Index (VPI) is used for indicator 23 (*public participation*) and represents the average number of memberships in voluntary organizations as measured for EU-countries in 2003 (EFILWC 2006). We have updated this indicator by using the percentage of people involved in unpaid work (EFILWC 2012). For non-EU countries a best estimate is provided (Eq. 4) based on the high correlation with the World Bank indicator *Rule of Law* (n=27; r=0.84; p <0.0000001).

$$\textit{Public participation} \text{score} = 0.0657 * \text{score for } \textit{Rule of Law} – 2.2278 \qquad (4)$$

4.2.3 Indicator Boundaries

The indicators of the CBF are standardized according to the min-max method, by using percentages or by a self-assessment scoring method as explained in the City Blueprint questionnaire (EC 2015). The min-max standardization method is sensitive for outliers that may result in unrealistic scores and therefore indicator boundaries have been reviewed. For instance, indicator 16 (*water system leakages*) measures the leakage rate of the drinking water distribution system. The indicator boundaries for leakage have been set at 0 and 100 %, respectively. Consequently, 0 % is equivalent to a completely leaking water distribution system which results in a low variance of this indicator. Therefore, the maximum boundary of water leakage has been arbitrarily reset at 50 %. The same holds for indicator 15 (*average age sewer system*), where the maximum age of the urban sewers has been lowered from 100 to 60 year. For large datasets (n>100), the average of the lower and upper 10 % have been used as minimum and maximum. This is done for indicator 4 (*solid waste collected*), 17 (*operation cost recovery*) and 18 (*green space*).

4.2.4 Water Footprint Indicators

Based on constructive criticism from local water authorities concerning the use of the Water Footprint (WF) concept (used in the former category *water security*), it has been decided to discontinue their use. The WF describes the total volume of water over the full supply chain

that is needed to produce a product or that is used by a country (Hoekstra et al. 2009). Water imports and exports of a country are highly dependent on many social-economic processes and national and global trends on which the local water authorities have a negligible influence. Moreover, the indicator *water scarcity* and *water self-sufficiency* are largely determined by the total renewable water resource which is abundant or not, regardless of the interventions by local water authorities. In fact, temperature, rainfall, soil type, river course, etc., largely determine the total renewable water resources.

4.2.5 Solid Waste

Cities are prone to water pollution due to their highly efficient drainage systems that quickly collect and discharge polluted water. Cities are the largest source of plastic waste that enters the oceans via rivers and canals. About 280 million tonnes of plastics ends up in the oceans annually, where it photodegrades into small particles and affects marine ecosystems (Derraik 2002; Sigler 2014). The degradation of plastic waste in landfills is approximately 1 to 5 % during 100 years (Bez et al. 1998). Urban solid waste treatment is therefore a key performance-oriented aspect that determines the water quality in cities, rivers and oceans. According to the European Commission (EC 2008), the priority order for waste reduction is waste prevention, reuse, recycling, recovery and disposal. Hence, indicator 4 (*solid waste collected*), 5 (*solid waste recycled*) and 6 (*solid waste energy recovered*) have been included.

4.3 Step 3: Indicator Rearrangements and Aggregation Method

The contribution of the indicators and categories to the BCI are currently highly variable. Indicators with low variances contribute less to the BCI. Moreover, the variances differ strongly and the number of indicators per category are not equal (Koop and Van Leeuwen 2015b). However, an equal contribution of each category and indicator is strived for. The final rearrangement of the indicators and categories is shown in Table 2. Currently, no particular penalty for unbalanced scores are given, and therefore the need to improve the achievements for low scoring indicators needs to be addressed (JRC 2014).

4.3.1 Basic Water Services

An indicator intra-correlation analysis revealed that the indicators *safe sanitation*, *sufficient to drink* and *drinking water quality* strongly correlate (Koop and Van Leeuwen 2015b). Access to proper drinking water and improved sanitation are basic water services which are united into a new category, i.e., category III (*basic water services*). The remaining indicators in the former category *sanitation*, all deal with wastewater treatment and the category has been renamed to 'wastewater treatment' (category IV; Table 2). This is in accordance with the ISO37120, which is a much broader urban indicator framework that also includes a 'water and sanitation' and 'wastewater' category (ISO 2014).

4.3.2 Climate Robustness

The correlation coefficient between the indicators *climate commitment* and *adaptation measures* is high (r=0.93). Given the similar ordinal assessment method, it is most

Table 2 Overview of the performance indicators of the improved City Blueprint Framework (CBF) as described in step 2 and 3 of the revision (Fig. 1). Indicators in bold are new and indicators with adjusted scaling or new data bases are in italics. The other indicators have not been adjusted

I. Water quality	**1. Secondary WWT**
	2. Tertiary WWT
	3. Groundwater quality
II. Solid waste treatment	**4. Solid waste collected**
	5. Solid waste recycled
	6. Solid waste energy recovered
III. Basic water services	7. Access to drinking water
	8. Access to sanitation
	9. Drinking water quality
IV. Wastewater treatment	*10. Nutrient recovery*
	11. Energy recovery
	12. Sewage sludge recycling
	13. WWT energy efficiency
V. Infrastructure	14. Stormwater separation
	15. Average age sewer
	16. Water system leakages
	17. Operation cost recovery
VI. Climate robustness	**18. Green space**
	19. Climate adaptation
	20. Drinking water consumption
	21. Climate-robust buildings
VII. Governance	22. Management and action plans
	23. Public participation
	24. Water efficiency measures
	25. Attractiveness

likely that these indicators overlap. Furthermore, given the high correlations with indicators 19, 20, 22 and 23 ($r > 0.71$), it is presumable that the indicator *climate commitment* is redundant and has therefore been removed (Koop and Van Leeuwen 2015b). Although climate change impacts are complex and ubiquitous, three climate vulnerabilities with particular reference to urban areas have been identified, i.e., UHI, water scarcity and flooding (EEA 2012). The UHI exacerbates heat waves in cities because the cooling effect of vegetation is replaced by surfaces sealed with concrete, asphalt and stone (EEA 2012). Green and blue areas store rainwater and evaporate this water, thereby mitigating heat waves and storm events. In addition, green and blue areas alleviate air pollution, increase the city's recreational value and reduce water polluted (Li et al. 2014; Jia et al. 2013; Jonker et al. 2014; Czemiel Berndtsson 2014). Therefore, the share of blue and green area (%) is added as a new indicator in category VI (*climate robustness*), shown in Table 2. Climate change will also increase the urban vulnerability to water scarcity (EEA 2012). The domestic and industrial use of drinking water is an adequate indication of how cities combat water scarcity. Therefore indicator 20 (*drinking water consumption*) is also included in category VI (*climate robustness*) (Table 2).

4.3.3 Governance

At this stage of the framework rearrangement, the former category *biodiversity and attractiveness* only includes indicator 25 (*attractiveness*), because the indicator *biodiversity* has previously been removed. Indicator 25 (*attractiveness*) measures the incorporation of blue-green areas which is mainly the result of urban planning by local authorities, the local community and private companies (shops, factories, restaurants, bars etc.) who want to shape an attractive place to live. The relation with governance is also indicated by the correlations with the indicator 22 (*management and action plans*) (r=0.53), 23 (*public participation*) (r=0.61) and 24 (*water efficiency measures*) (r=0.74). *Water efficiency measures* assesses to what extent water efficiency measures are applied. Because correlated indicators 22, 23, 24 and 25 all assess how local authorities manage water issues, these indicators have been united into category VII (*governance*).

4.3.4 Infrastructure

The former category *infrastructure* is only poorly accounted for given the large maintenance cost and large global investment deficit in water infrastructure (AWWA 2001; Cashman and Ashley 2008). Therefore indicator 16 (*water system leakages*) has been added because it is suitable to represent the maintenance of the drinking water infrastructure. In contrast with data on total investments in water infrastructure, data of operation costs and revenues of drinking water and sanitary services is often available (IBNET 2015; OECD 2010). The ratio of the total yearly operating revenues divided by the operating costs of drinking water and sanitation services is an important indicator of the financial state of the local water authorities and their ability to make the necessary investments in infrastructure (OECD 2015). Hence, indicator 17 (*operation cost recovery*) is added to strengthen category V (*infrastructure*), given in Table 2.

4.3.5 Aggregation Method

For composite indices, issues of weighting and aggregation are sensitive and subjective (EPI 2010). It should be recognized that assigning explicit weightings, by definition, represents only one viewpoint. Therefore, no indicator or category weightings are applied. Moreover, the implicit weighting, due to correlations and/or differences in variances are addressed before the indicators are aggregated.

Most frequently used aggregation methods are the arithmetic and geometric mean. The arithmetic mean gives no particular penalty for unbalanced scores, and consequently does not address the urgent need to improve achievements for the lowest scores (JRC 2014). However, it is essential to regard water management in an integrative way, e.g., increasing access to sanitation greatly improves human hygiene but without adequate investments in WWT, this leads to a strong emission increase in hazardous pollutants and nutrients. Hence, a high score for access to sanitation should not fully compensate a low score for WWT coverage (Ligtvoet et al. 2014).

Since a geometric mean can be defined as the nth root of the product of n numbers or as the anti-log of the sum of logs divided by the number of samples and the log zero (0) is not defined, the calculation of the geometric mean method requires strictly positive values. It is therefore chosen to re-standardize the indicators to a 1–11 score, aggregate the indicators with

the geometric mean and finally subtract 1 point from this score. In this way, balanced indicator performances are rewarded.

4.4 Examples

For all 45 cities data have been gathered for the analyses of their TPF and improved CBF. In this section examples of only three cities are presented, i.e., Dar es Salaam, Melbourne and Amsterdam. The TPF is shown in Table 3. The overall Trends and Pressure Index (TPI) for Dar es Salaam, Melbourne and Amsterdam are 2.7, 1.1 and 1.2 respectively. The improved City Blueprints for these cities are shown in Fig. 3. The new BCI for Dar es Salaam, Melbourne and Amsterdam are 1.3, 5.4 and 8.3 respectively. The performance ranking of these cities is shown for each category (Fig. 4).
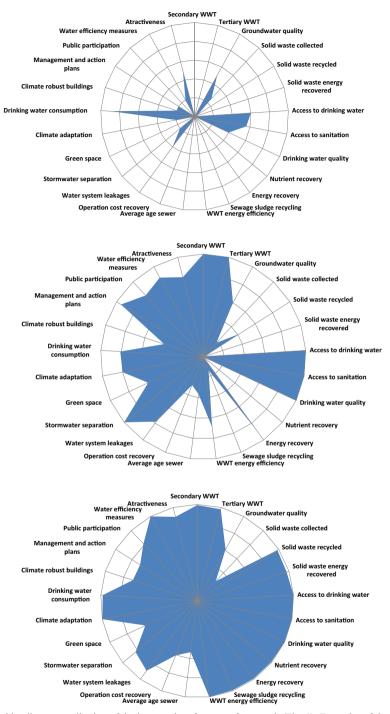
5 Discussion
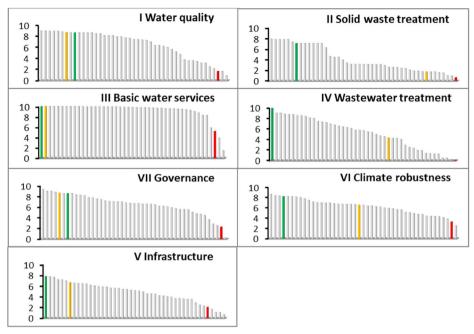
5.1 City Blueprint Improvements

We have developed two separated indicator frameworks that embody the distinction between trends and pressures (TPF) and IWRM performance of a city (CBF). In the TPF only indicators that are of concern or great concern (3 or 4 points) are explicitly communicated to the stakeholders (Table 3). The CBF is essential to show the potential gain possible by sharing knowledge, experiences and best practices amongst cities. Moreover, it more accurately depicts the own activities and efforts of cities to improve the sustainability of their IWRM and how they can alleviate environmental pressures such as emissions of poorly treated wastewater and solid waste. The TPF provides a wider context, which is key in obtaining insight into the limitations and windows of opportunities to improve urban IWRM. Finally, the categories of the 45 cities are averaged and ranked

Table 3 Trends and Pressures Framework (TPF) of Dar es Salaam, Melbourne and Amsterdam with their concern scores: 0 (no concern), 1 (little concern), 2 (medium concern), 3 (concern), and 4 (great concern)

		Dar es Salaam	Melbourne	Amsterdam
Social	1. Urbanization rate	4	1	1
	2. Burden of disease	3	1	0
	3. Education rate	3	0	1
	4. Political instability	2	1	1
Environmental	5. Water scarcity	2	1	1
	6. Flood risk	3	2	3
	7. Water quality	1	2	2
	8. Heat risk	3	4	1
Financial	9. Economic pressure	4	0	1
	10. Unemployment rate	1	1	1
	11. Poverty rate	4	0	0
	12. Inflation rate	3	2	1

Fig. 3 Spider diagram application of the improved performance framework (Fig. 1). Examples of three spider diagrams based on 25 performance indicators for Dar es Salaam (top), Melbourne (centre) and Amsterdam (bottom). The geometric mean of the indicators, i.e., the BCI, are 1.3, 5.4 and 8.3, respectively

Fig. 4 Category ranking of the City Blueprints of Dar es Salaam (*red*), Melbourne (*orange*) and Amsterdam (*green*). The arithmetic average of the indicator scores for each of the seven categories (Table 2) are ranked from high to low for each of the 45 municipalities and regions. This ranking is part of the application of the performance framework (Fig. 1)

in order to provide a quick overview of potential improvements compared to other cities (Fig. 4). These simple graphical representations allow for a quick overview of cities on their path to become water-wise and climate prove.

5.2 Limitations

Only publicly available data is added to this improved CBF in order to promote transparency, and to reduce time and costs. City scale data concerning urban IWRM appeared to be particularly scarce. In fact, this information is often available, but publicly inaccessible which hampers city-to-city learning (EEA 2014b). Moreover, existing urban water-related indicators are often not standardized, consistent, or comparable over time and between cities (ISO 2014). For a considerable number of indicators national data are used because local data is not publicly available for all cities. This limits the accuracy of city assessments, especially in large countries with high regional variety.

Basic statistics obtained from the 45 cities have been used to reconstruct the CBF and to arrive at an approximately proportional contribution of all indicators and categories. However, the 45 cities that are used for this statistical analysis have a distribution bias as most cities are located in North-West Europe and are therefore not representative for the global urban challenges. This is a limitation of our work. Hence, it should be taken into account that the actual variance of the indicators may differ from the output of cities that have been analysed. For instance, the variance of

category 3 (*basic water services*) and 7 (*governance*) is expected to be larger if the cities would really represent a global sample, i.e., if cities from developing countries would not be underrepresented.

5.2.1 Indicator Limitations

The data for the baseline assessment proposed in this paper is gathered by means of a questionnaire (EC 2015) and by using publicly available data. In order to include a large number of cities of different size and geography, the indicator framework is limited by the information that was available. Hence, the set of indicators can and should be extended for some cities. Public data concerning flood risks appeared to be particularly sparse. Information on urban flood vulnerability is available, i.e., vulnerability to river peaks and sea level rise (Jongman et al. 2014; EEA 2012). However, these data do not represent flood protection performances. Hence, these indicators are included in the TPF. Ideally, a flood return interval is used to quantify the performance of flood defence. However, flood return intervals are not consistently reported worldwide, let alone, calculated in comparable manner.

The percentage of uncollected solid waste is inconsistently reported. Only for a very few cities, it was more than zero, preventing it to become a suitable comparative indicator. However, uncollected solid waste can strongly contribute to the release of a variety of pollutants such as heavy metals, persistent bio-accumulative chemicals, pesticides, pharmaceuticals and plastic (Katsanevakis 2011). However, efforts to reduce water polluting activities such as landfilling and solid waste production are explicitly included.

Another major cause of urban water pollution is stormwater runoff. This pollution pathway is related to traffic intensity and uncollected solid waste (Czemiel Berndtsson 2014; Revitt et al. 2014). Urban soil permeability or the use of best practices to reduce or filter stormwater runoff, e.g., by biofilters, infiltration ponds or bioswales, may be insufficiently addressed in the CBF due to limited data availability on soil permeability. Only indicator 18 (*green space*) and 19 (*climate adaptation*) implicitly address these issues. Hence, a supplementary indicator that assesses the application of measures to decrease and filter stormwater runoff could be added.

The min-max method can be sensitive for extreme outliers that may disrupt the scoring. Therefore the average of the lower and upper 10 % from a large data set (n>100) is taken as the minimum and maximum for indicators 4 (*solid waste collection*), 17 (*operation cost recovery*) and 18 (*green space*). However, for drinking water consumption this was hindered because there was no large dataset that included residential, commercial, industrial and public purposes. Often only domestic water consumption data is provided which represents only 10 % of the total drinking water consumption in the EU (ISO 2014). Likewise, indicator 15 (*average age sewer*) is prone for outliers because minimum and maximum numbers are taken from a limited dataset.

Data coverage of the selected set of indicators is high. Only the operation cost recovery (ratio) of Helsinki and data according to the EEA (2012) assessment method for indicator 18 (*green space*) were not available for non-EU cities. In most cases a realistic default value of 20 % green space is taken (e.g., for Ho Chi Minh City and Istanbul) and only for Melbourne we arbitrarily set this score equal to that of Amsterdam. Finally, the operation cost recovery for Helsinki has been arbitrarily set at 1, as data have not been provided.

5.2.2 Water Infrastructure Investment Deficit

Upgrading of water infrastructure is crucial for water security in cities (OECD 2015). Water infrastructure investment requirements are already high in developed countries (yearly 0.35– 1.2 % of GDP) and even higher for developing countries (yearly 0.71–6.30 % of GDP) (Cashman and Ashley 2008). Hence, the state of the water infrastructure network (indicator 15 *average age sewer*) is decisive for the city's financial performance.

As an indication of the maintenance of the sewer system in a city, we have divided the average by an assumed sewer lifespan. This is an inaccurate approximation since local circumstances that determine the sewer lifespan are not incorporated. A first improvement could be to determine a site-specific maximum sewer lifespan and compare this with the current site-specific average age. A more advanced approach would be to calculate the yearly sewer maintenance investment requirement (Equation 5) as proposed by Prof. Dr. Bosseler (personal communication). The infrastructure lifespan and system asset value should be calculated for each city. By using equation (5), an annual investment can be calculated that should be reserved for long-term infrastructure maintenance. The actual investment in infrastructure can be scored as a fraction of this annual investment requirement.

$$\text{Investment requirements } (€/\text{year}) = \frac{System\ Asset\ Value(€)}{Lifespan(years)} \tag{5}$$

6 Conclusions

The goal of this study is a methodological review of the City Blueprint indicator framework to improve the assessment of the sustainability of IWRM in cities (Fig. 1). The results of the application of this improved method has been reported in this journal (Koop and Van Leeuwen 2015a). This revision was necessary to better emphasize cities' opportunities to envision, develop and implement stepwise measures to transform towards water-wise or water sensitive cities. The following changes have been made:

1. A distinction between descriptive and performance-oriented indicators has been made by developing a Trends and Pressures Framework (TPF; on which the city's IWRM has a negligible influence) and improving the city-level IWRM performance framework, i.e., the City Blueprint Framework (CBF).
2. The TPF includes the following social, environmental and financial indicators: urbanization rate, burden of disease, education rate, political instability, water scarcity, flood risk, water quality, heat risk, economic pressure, unemployment rate, poverty rate and inflation rate. The data are publicly available (Table 1).
3. We distinguish 5 ordinal classes, varying from no concern to great concern, for each of these 12 TPF indicators.
4. In the revised CBF, seven indicators have been added, i.e., secondary and tertiary wastewater treatment, operation cost recovery, green space and three indicators concerning *solid waste treatment* (Table 2).
5. Adjusted scaling or new databases are used for the following CBF indicators: nutrient recovery, energy recovery, sewage sludge recycling, average age sewer, water system leakages and public participation (Table 2).

6. The geometric aggregation method has been chosen to calculate the Blue City Index for the 25 indicators of the CBF.

7. We have applied this new CBF, TPF and BCI to 45 cities in 27 countries (Koop and Van Leeuwen 2015a).

8. The focus on performance will enhance city-to-city learning, i.e., sharing of knowledge, experiences and best practices between cities. This is the ultimate goal of our EIP Water Action Group (EC 2015) as the need to improve IWRM in cities is crucial and the time window to do this, is closing rapidly (OECD 2015; Van Leeuwen 2013).

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