


The challenges of water, waste and climate change in cities

S. H. A. Koop^{1,2} · C. J. van Leeuwen^{1,2} 

Received: 21 October 2015 / Accepted: 5 January 2016 / Published online: 1 February 2016
© The Author(s) 2016. This article is published with open access at Springerlink.com

Abstract Cities play a prominent role in our economic development as more than 80 % of the gross world product (GWP) comes from cities. Only 600 urban areas with just 20 % of the world population generate 60 % of the GWP. Rapid urbanization, climate change, inadequate maintenance of water and wastewater infrastructures and poor solid waste management may lead to flooding, water scarcity, water pollution, adverse health effects and rehabilitation costs that may overwhelm the resilience of cities. These megatrends pose urgent challenges in cities as the cost of inaction is high. We present an overview about population growth, urbanization, water, waste, climate change, water governance and transitions. Against this background, we discuss the categorization of cities based on our baseline assessments, i.e. our City Blueprint research on 45 municipalities and regions predominantly in Europe. With this bias towards Europe in mind, the challenges can be discussed globally by clustering cities into distinct categories of sustainability and by providing additional data and information from global regions. We distinguish five categories of sustainability: (1) cities lacking basic water services, (2) wasteful cities, (3) water-efficient cities, (4) resource-efficient and adaptive cities and (5) water-wise cities. Many cities in Western Europe belong to categories 3 and 4. Some cities in Eastern Europe and the few cities we have assessed in Latin America, Asia and Africa can be categorized as cities lacking basic water services. Lack of water infrastructures or obsolete infrastructures, solid waste management and climate adaptation are priorities. It is concluded that cities require a long-term framing of their sectoral challenges into a proactive and coherent Urban Agenda to maximize the co-benefits of adaptation and to minimize the cost. Furthermore, regional platforms of cities are needed to enhance city-to-city learning and to improve governance capacities necessary to accelerate effective and efficient transitions

✉ C. J. van Leeuwen
Kees.van.Leeuwen@kwrwater.nl;
<http://www.kwrwater.nl>

¹ KWR Watercycle Research Institute, Groningenhaven 7, 3433 PE Nieuwegein, The Netherlands

² Copernicus Institute for Sustainable Development and Innovation, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

towards water-wise cities. These learning alliances are needed as the time window to solve the global water governance crisis is narrow and rapidly closing. The water sector can play an important role but needs to reframe and refocus radically.

Keywords Water governance capacities · Sustainability transitions · Urban Agenda · Smart cities · City Blueprints · Circular economy · HABITAT III

1 Introduction

1.1 Population growth

The world population is projected to increase by more than one billion people within the next 15 years, reaching 8.5 billion in 2030, and to increase further to 9.7 billion in 2050 and 11.2 billion by 2100 (UN 2015). Approximately 60 % of the global population lives in Asia (4.4 billion), 16 % in Africa (1.2 billion), 10 % in Europe (738 million), 9 % in Latin America and the Caribbean (634 million), and the remaining 5 % in Northern America (358 million) and Oceania (39 million). Population growth patterns are different across the globe. Figure 1 shows population growth in some world regions from the year 1600 to 2100 (Klein Goldewijk et al. 2010; UN 2015a). Many countries in Africa are still growing exponentially. This implies that their claims on resources also increase rapidly. In Western Europe and India+ (India, Bangladesh, Nepal, Sri Lanka, Bhutan, Pakistan, Afghanistan and Maldives), population growth is gradually levelling off (logistic growth), while in China growth will soon decline due to the one-child family policy. This policy was introduced in 1979 to halt the rapid growth in the Chinese population, and it included late marriage and childbearing (delaying the start of reproduction) as well as the restriction on

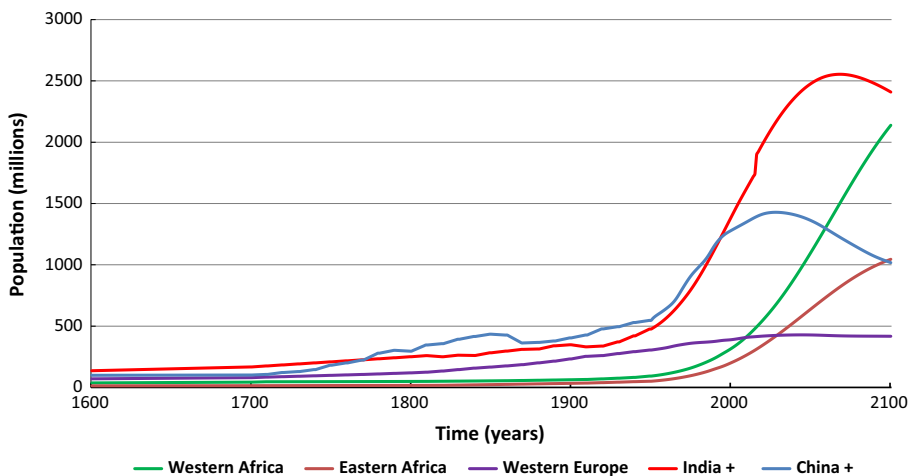


Fig. 1 Total population estimations of India+ (India, Bangladesh, Nepal, Sri Lanka, Bhutan, Pakistan, Afghanistan and Maldives), China+ (China, Hong Kong, Macao and Mongolia), Eastern Africa, Western Africa and Western Europe based on the HYDE 3.1 database (Klein Goldewijk et al. 2010), and the UN medium variant of the world population predictions (UN 2015a)

family size to just one child per family with high penalties for infringement (Hesketh et al. 2005). In fact, the maximum population densities in China+ (China, Hong Kong, Macao and Mongolia), Western Europe and India+ are expected in the year 2026 (1428 million), 2045 (424 million) and 2069 (2554 million), respectively (UN 2015a).

Urbanization will continue in both the more developed and the less developed regions so that, by 2050, urban dwellers will likely account for 86 % of the population in the more developed regions and for 64 % of that in the less developed regions. Overall, the world population is expected to be 67 % urban in 2050 (UN 2012). Thus, urban areas of the world are expected to absorb all the population growth over the next decades.

1.2 City Blueprint methodology

The development of the City Blueprint methodology to assess the sustainability of integrated water resources management (IWRM) in municipalities and regions started in 2011 (Van Leeuwen et al. 2012). A baseline assessment was developed as part of the strategic planning process in cities as described in the training modules developed in the SWITCH project (managing water for the city of the future). The assessment was kept as short, clear and simple as possible. The strategic planning process and the role of the City Blueprint are provided in Fig. 2. The indicators in the City Blueprint are based on the 3 Ps (People, Planet and Profit) in the water cycle (Van Leeuwen et al. 2012, Koop and Van Leeuwen 2015a). Use has been made of several other assessment frameworks (Van Leeuwen et al. 2012), including the Green City Index (2015). Similar assessment schemes have been published by SDEWES (2015).

The sustainability of IWRM is assessed in an interactive process involving the most important IWRM actors (Philip et al. 2011). This interactive approach has been used for the assessment of all cities, except for Rotterdam, Ankara and London. For these cities, an extensive literature search was completed. For all other cities, a comprehensive questionnaire was completed by municipalities and regions, which takes them a few days

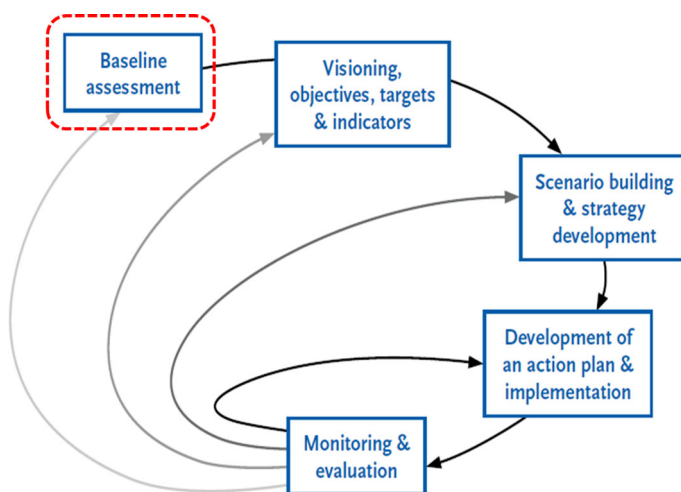


Fig. 2 Function of the City Blueprint (red box) in the strategic planning process for IWRM according to SWITCH (Philip et al. 2012)

(European Commission 2015a). The City Blueprint offers cities a threefold benefit: (1) an interactive quick scan of their own water cycle, (2) access to best practices in other cities (Koop et al. 2015) and (3) participation in an international platform (European Commission 2015a). After the completion of the questionnaire, a radar chart of all 25 performance indicators (the City Blueprint) and the Blue City Index (BCI) are provided both varying from 0 (concern) to 10 (no concern). This initiative has been scaled up to an action under the flag of the European Innovation Partnership on Water of the European Commission (European Commission 2015a) in the framework of the European Blueprint for water (European Commission 2012). The City Blueprint provides municipalities and regions with a practical and broad framework to define steps towards realizing a more sustainable and resilient water cycle in collaboration with key stakeholders.

1.3 Outline of this study

The aim of this study is to present an overview of the challenges of water, waste and climate adaptation in cities and to link the City Blueprint activities to major developments such as: the challenges of urbanization (Sect. 2), water governance (Sect. 3) and transitions in cities (Sect. 4). In Sect. 5, we summarize our work on City Blueprints and discuss their role in learning alliances of cities (Sect. 6). Concluding remarks are provided in Sect. 7.

2 Urbanization and the dynamics of the city

2.1 Homes

Most people live in cities. There are more than 400 big cities (urban areas with more than one million inhabitants) and 23 megacities (metropolitan areas with a population of more than 10 million). Most of these megacities are in Asia (UN 2012). The United Nations (UN) estimates that 54 % of all people live in cities, and by 2050, this will increase to 66 % (UN 2015a). In developed countries, this percentage is even higher (more than 80 %). Global urbanization is taking place at a high speed. In 1970, for example, there were only two megacities (Tokyo and New York); in 1990, there were 10; in 2011, there were 23, and by 2025, there will be 37 megacities. Tokyo, the largest megacity, will grow from 37 million to about 40 million people in 2025 (UN 2012).

The United Nations (UN 2015a) estimates that between 2015 and 2050 the world population will grow from 7.32 to 9.55 billion. At the same time, the population in cities will increase from 3.96 to 6.34 billion, while the number of people living in rural areas will decline. Due to population growth and migration from rural areas to cities, approximately 190,000 people per day will need to find a new place to live. In other words, over the next 40 years, we will build approximately 3000 big cities with a population size of Amsterdam. It should be noted that there are major differences in the rate of population growth and urbanization in different parts of the world (UN 2012, 2015a). Developing countries account for 93 % of the urbanization globally, 40 % of which is the expansion of slums. By 2030, the urban population in Africa and Asia will double (UNESCO 2015a).

2.2 Work

Cities play a prominent role in economic development. More than 80 % of the gross world product (GWP) comes from cities. Only 600 urban areas with just 20 % of the world population generate 60 % of the GWP (Dobbs et al. 2011). Cities are therefore also job generators and centres of communication, innovation and creativity. They also play a large part in social and cultural matters (European Commission 2011; BAUM 2013). Cities can also take the lead in sustainable development as they offer many economies of scale per head of the population in terms of raw material use, energy consumption, waste recycling and transport (BAUM 2013).

The continued acceleration of change or ‘rapidification’ of our planet, our life and the global economy is higher than ever (Francis 2015). The transformation of China due to urbanization and industrialization is taking place on a scale 100 times greater and ten times faster as compared to UK a century ago (Dobbs et al. 2012). This comes with unavoidable consequences (Van Leeuwen 2008). To illustrate this, two examples are provided: one looking back and the other forward: first of all, a backward glance based on the turnover of the chemical industry over the last 10 years. In 2003, the production of the chemical industry was roughly equally divided between Europe, North America and the rest of the world. In 10 years’ time sales, figures have almost doubled to €3156 billion, but the hub has shifted to Asia with a share of 57 % in 2013 (CEFIC 2014).

The second example has been taken from a report by Dobbs et al. (2012). Emerging cities create opportunities. That is why entrepreneurs increasingly focus on cities with great economic growth potential as in 2025 one billion new consumers are expected. This will create many opportunities and is undoubtedly the main reason why people are moving on such a massive scale to the city. There will be an acceleration in the shift of the economic hub from the old developed countries to the new developing or transitioning countries, particularly in Asia. The population growth of Chinese cities until 2025 and the accompanying growth in gross domestic product (GDP) and drinking water supply needs has been estimated at 30.9, 39.7 and 25.6 %, respectively, whereas growth in European cities has been estimated at 1.8, 5.7 and 1.7 %, respectively. This means that after about five centuries (since the discovery of America), Asia will again become the global economic epicentre (Dobbs et al. 2012).

2.3 Challenges of urbanization

The concentration of homes and employment in cities also has its downside. Cities currently take up about 2 % of the land surface on Earth, but account for 60–80 % of the energy consumption and 75 % of global CO₂ emissions (UN 2013a). Roughly the same percentage will also apply to the use of raw materials (e.g. metals, wood, plastics) for infrastructure, houses, cars and numerous other consumer items. Cities are concentrated centres of production, consumption and waste (Grimm et al. 2008; Bai 2007). Ecological studies of cities have shown that they sometimes exceed their environmental footprint by a factor 10–150 (Doughty and Hammond 2004). This creates enormous pressure not only on water supply, solid waste recycling and wastewater treatment (Grant et al. 2012), but also on nature and the built environment too, including soil, air and water pollution (UN 2013a; Hoekstra and Wiedman 2014). Water pollution reduces the availability of healthy water (Schwarzenbach et al. 2006; WHO 2008; Van Leeuwen and Vermeire 2007). Cities are therefore becoming increasingly dependent on rural areas for the supply of energy, water,

building materials and food, as well as for the removal of waste and waste substances (OECD 2015a; UN 2014). A summary of some of the challenges in cities is provided in Fig. 3.

The consequences of urbanization extend to areas far beyond the city, areas which are vital to supply cities with important ‘ecosystem services’ (OECD 2015a). An example is provided by the megacity Istanbul, where water is now supplied from a basin by a 180-km-long pipeline (Van Leeuwen and Sjerps 2015a). Habitat preservation, i.e. the conservation of the forests surrounding Istanbul—vital habitats for the water supply—is extremely important for the future of Istanbul (Atelier Istanbul 2012).

2.4 Water challenges in the city

Drinking water consumption in cities makes up a small fraction of the total water footprint. For example, people in the Netherlands use about 2300 m³ of water per person per year of which 67 % is for agriculture, 31 % is used in industry, while only 2 % makes up household water (Van Oel et al. 2009). This means that water challenges in cities need to be solved predominantly by actors outside the traditional water sector. In fact, half of all cities with populations greater than 100,000 are located in water-scarce basins. In these basins, agricultural water consumption accounts for more than 90 % of all freshwater depletions (Hunger and Döll 2008; Richter et al. 2013). In a critical analysis, Richter et al. (2013) point out that nearly all water used for domestic and industrial purposes is eventually returned to a water body. For instance, toilets are flushed and purified wastewater as well as cooling water in power plants is often returned to rivers. Because much of this



Fig. 3 Megatrends pose urgent challenges in cities (Van Leeuwen 2013)

water is not consumed, efforts to reduce urban water use or to recycle water with the aim to alleviate water scarcity per se, hardly makes any difference. In total, the domestic, industrial and energy sectors account for less than 10 % of global water consumption (Richter et al. 2013; Hoekstra et al. 2012). Of course, proper urban use and reuse of water, as well as adequate sanitation, contribute significantly to pollution reduction, local water availability, as well as to energy efficiency, energy and nutrient recovery.

Hoekstra et al. (2012) estimate that agriculture accounts for 92 % of the global blue water footprint. Land, energy and climate studies have shown that the livestock sector plays a substantial role in deforestation, biodiversity loss and climate change. Livestock also significantly contributes to humanity's water footprint, water pollution and water scarcity (Jalava et al. 2014; Hoekstra 2014). Furthermore, the Food and Agriculture Organization of the United Nations (FAO) estimates that 32 % of all food produced in the world was lost or wasted in 2009 (Lipinski et al. 2013; FAO 2011a). Therefore, consumers, i.e. citizens, can play a major role in the reduction in the global water footprint by both reducing the fraction of animal products in their diets and by curbing their food waste.

With a changing climate comes a greater demand for proactive adaptation processes, as well as knowledge of how adaptation policies and measures could be implemented successfully. Accidents often lead to major policy changes. In 1953, almost 2000 people drowned in the Netherlands. As a result of this catastrophe, a long-term plan was devised, the Delta Plan, with a Delta Fund, and a Delta Commissioner appointed, reporting directly to the Dutch Minister-President (Delta programme 2013). Another example of a reactive adaptation policy can be observed in the city of Melbourne. Melbourne is a city of extremes: floods due to excessive rainfall, but drought too. A 10-year period of drought has recently come to an end. This has forced the city to take rigorous measures: (1) the construction of a costly desalination plant as backup for drinking water supply, (2) rain-water harvesting and (3) the reuse of wastewater (Van Leeuwen 2015). Melbourne has become 'water sensitive' or water-wise (Brown et al. 2009), and the citizens 'do their bit', e.g. by limiting water use and installing rainwater tanks on a wide scale to make good use of the rain when it does fall.

Disasters quickly raise awareness, whether that be about defending against flooding or dealing with drought (Koop and Van Leeuwen 2015a, b). Hence, adaptation measures are mainly reactive (Amundsen et al. 2010; Reckien et al. 2015), ad hoc, and often ineffective and expensive (UNEP 2013). Globally, the main challenge is to move from reactive measures to proactive transitions, by taking bold decisions based on a cohesive long-term process as shown in Fig. 2.

2.5 Solid waste and water

Cities generate massive amounts of solid waste. Poor waste management, ranging from non-existing collection systems to ineffective disposal, causes air, water and soil contamination. Open and unsanitary landfills contribute to contamination of drinking water and increase infection and transmit diseases. Managing solid waste is another challenge of urban areas of all sizes, from megacities to the small towns and large villages (UN-Habitat 2010).

Plastics easily enter rivers and ultimately oceans. Jambeck et al. (2015) calculated that 275 million metric tons of plastic waste was generated in 192 coastal countries in 2010. Approximately 1.7–4.6 % of this plastic enters oceans (Jambeck et al. 2015). Plastic waste does not readily biodegrade but degrades into smaller pieces that affect marine ecosystems (Derraik 2002). The plastics form 'soups' in five major ocean gyres: two in the Pacific, one

in the Indian and two in the Atlantic and affect many marine animals by ways of ingestion (Zarfl et al. 2011; McFedries 2012). Also consumer products contribute to the emission of microplastics to surface water such as cosmetics and personal care products, cleaning agents, paint and coatings (Van Wezel et al. 2015). Recently, a detailed study was made for the river Rhine, one of the largest European rivers. Microplastics were found in all samples, with 892,777 particles per km² on average. These microplastics concentrations were diverse across the river, reflecting various sources and sinks such as wastewater treatment plants, tributaries and weirs (Mani et al. 2015).

Recycling leads to substantial resource savings (EMF 2014, 2015a) and to significant reductions in greenhouse gas (GHG) emissions. GHG emissions from open dump land-filling are about 1000 kg CO₂-eq. tonne⁻¹ of solid waste, whereas this can be largely reduced to 300 kg CO₂-eq. tonne⁻¹ for conventional landfilling. Actually, it can even be a net sink of carbon when most material is recycled or the energy is recovered (Manfredi et al. 2009). The global GHG emissions of solid waste disposal sites are estimated to be approximately 5–20 % of the global anthropogenic methane emission, which is equal to about 1–4 % of the total anthropogenic GHG emissions (IPCC 2006).

The order of preference of managing waste also known as the Lansink's ladder has been laid down in the Dutch Environmental Management Act (VROM 2001) and subsequently across Europe, as the waste hierarchy in the Waste Framework Directive (2008). The waste hierarchy is a preference order from: prevention, preparing for reuse, recycling, other recovery (e.g. energy recovery) and disposal.

Recently, the European Commission announced a plan for the circular economy. One of the reasons is that Europe currently loses around 600 million tonnes of materials contained in waste each year, which could potentially be recycled or reused. On average, only 40 % of the waste produced by EU households is recycled ranging from 5 % in some areas to 80 % in others. Turning waste into a resource is an essential part of increasing resource efficiency and part of this circular economy package (European Commission 2015b; EMF 2015b).

Solid waste data in many cities are largely unreliable. Available data show that cities can improve on their solid waste management as waste collection rates for cities in low- and middle-income countries range from 10 % in peri-urban areas to 90 % in commercial city centres (UN-Habitat 2010). Even in Europe, recycling rates are rather low (EEA 2013). As the sustainability of IWRM in municipalities and regions is intrinsically linked to proper solid waste management, it was decided to include the following three indicators in the improved City Blueprint framework (Koop and Van Leeuwen 2015a), i.e. solid waste collected (the per capita non-industrial solid waste that is collected; kg/cap./year), solid waste recycled (% of collected non-industrial solid waste that is recycled or composted) and solid waste energy recovery (% of collected non-industrial waste that is incinerated with energy recovery). This information has been gathered for 45 municipalities and regions (Koop and Van Leeuwen 2015b, c).

2.6 The cost of urban water infrastructure

Cities need to protect their citizens against water-related disasters (e.g. droughts and floods), to guarantee water availability and high-quality groundwater, surface water and drinking water. Cities also need to have adequate infrastructure in response to climate, demographic and economic trends (OECD 2015a). The cost of urban infrastructure is high. The UNEP (2013) estimates that for the period 2005–2030 about US\$ 41 trillion is needed to refurbish the old (in mainly developed countries) and build new (mainly in the

developing countries) urban infrastructures. The cost of the water infrastructure (US\$ 22.6 trillion) is estimated at more than that for energy, roads, rail, air and seaports put together. The wastewater infrastructure is responsible for the largest share of this 22.6 trillion. The report also warns that *'Sooner or later, the money needed to modernise and expand the world's urban infrastructure will have to be spent. The demand and need are too great to ignore. The solutions may be applied in a reactive, ad hoc, and ineffective fashion, as they have been in the past, and in that case the price tag will probably be higher than US\$ 40 trillion'*.

To support projected economic growth between now and 2030, McKinsey (2013) has estimated that the investments on global infrastructure need to increase by nearly 60 % from the US\$ 36 trillion spent on infrastructure over the past 18 years. Therefore, an investment of US\$ 57 trillion over the next 18 years is necessary. This is approximately 3.5 % of anticipated global GDP. These figures do not account for the cost of addressing the large maintenance and renewal backlogs and infrastructure deficiencies in many economies (McKinsey 2013). Cashman and Ashley (2008) have estimated the required annual expenditure on water and sanitation infrastructure for high-, middle- and low-income countries at, respectively, 0.35–1.2 %, 0.54–2.60 % and 0.71–6.30 % of the annual GDP.

Water goals have big costs but also big returns. Conservative estimates of global investments in a post-2015 water for sustainable development and growth agenda have been estimated (UN University 2013). Between 1.8 and 2.5 % of the annual global GDP is needed for implementation of water-related sustainable development goals. This would also generate a minimum US\$ 3108 billion in additional economic, environmental and social benefits, i.e. a net annual benefit of US\$ 734 billion.

2.7 Time is running out

In many countries, awareness of the urban challenges is low. Nevertheless, there are developments which cannot be ignored:

- The UN (2012) estimates that in 2025 about 2 billion people will have an absolute water shortage and that two-thirds of the world population will be affected by water scarcity. Estimates for 2030 assume 40 % more demand for water than is actually available (2030 Water Resources Group 2009).
- The world population growth and immigration will take place mainly in cities (UN 2012).
- Many cities lie in high-risk areas (UN 2012, 2013b). It is estimated that two-thirds of the world's largest cities will be vulnerable to rising sea levels. At the same time, many delta cities suffer from severe land subsidence. Consequently, the vulnerability of cities to both marine and fluvial flooding is expected to increase (Molenaar et al. 2015). It is predicted that the frequency, intensity and duration of extreme precipitation events will increase, as well as the frequency and duration of droughts (EEA 2012; Jongman et al. 2014).
- Large areas of productive agricultural land is fed by groundwater which is becoming increasingly depleted (UNEP 2007).
- Sea water intrusion, salinization of irrigated land, erosion and desertification are growing problems affecting global water and food security (FAO 2011b; UNESCO 2015a).

- Wastewater treatment in Asia and Africa is sparse, and nutrient emissions are projected to double or triple within 40 years as a result of rapid urbanization (Fig. 1). This will strongly enhance eutrophication, biodiversity loss, and threaten fisheries, aquaculture, tourism, and drinking water (Ligtvoet et al. 2014).
- Adequate sanitation remains a challenge for 2.5 billion people and lack of improvement will continue to lead to mortality, particularly among children (WHO 2008).

Sustainable water management is a major challenge. This is probably also the reason why the World Economic Forum (2014) ranked the water crisis and water-related risks as major global risks in terms of both probability and impact. Water is also high on the agenda of many other international organizations, such as the Organisation for Economic Co-operation and Development (OECD 2011a), the UN, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO 2011b).

2.8 Benefits of smart adaptation

The cost of preventable accidents in urban areas is high, and smart coherent transitions in cities are likely to prevent both human and capital losses. For instance, the overall economic impacts of water scarcity and drought events in the past 30 years were estimated at € 100 billion in the European Union (EU). From 1976–1990 to the following 1991–2006 period, the average annual impact doubled, rising to € 6.2 billion per year in the most recent years. The price tag of the exceptional European heat wave in 2003 was estimated at € 8.7 billion and caused up to 70,000 excess deaths over a four-month period in Central and Western Europe (EEA 2012).

Assets can be directly damaged by droughts, floods and severe storms. 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 European floods in 2013 are likely to increase in frequency from an average of once every 16 years to a probability of every ten years by 2050. A well-known example is the City of Copenhagen. During a two-hour thunderstorm, 150 mm of rain fell in the city centre on 2 July 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). Hurricane Katrina 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). Casualties, pollution and social stress are more difficult to quantify financially, but in general it can be concluded that the real costs of flooding in cities are seriously underestimated.

There is an increasing amount of information and evidence on the impacts of climate change and also on adaptation. However, information on the costs of inaction (future losses as a result of non-adaptation) remains limited, and there is an even larger gap for the costs of adaptation (EEA 2007, 2012). Preliminary estimates suggest that benefits often exceed costs. Taking advantage of opportunities related to urban renewal as well as designing multi-purpose solutions will often result in adaptation benefits exceeding the costs. More recent information shows that cost of inaction is significant. The global expected losses of the asset management industry as a result of climate change are valued at US\$ 4.2 trillion

(Economist Intelligence Unit 2015). An example of smart adaptation is provided by the City of Copenhagen. The cost of inaction for climate adaptation in Copenhagen has been valued at € 4–4.7 billion, and the climate adaptation cost at € 1.3–1.6 billion, resulting in future savings of € 2.6–3.2 billion (Leonardsen 2012).

The economic gain from materials savings alone is estimated at over a trillion US\$ a year. A shift to innovative reusing, remanufacturing and recycling products could lead to significant job creation. For instance, 1000,000 jobs have been created by the recycling industry in the EU alone (EMF 2014). These figures may even rise when also wastewater utilities will be considered as ‘profit centres’, i.e. as sources of energy (Grant et al. 2012; Van Leeuwen and Bertram 2013) and nutrients (Van Leeuwen and Sjerps 2015b), as phosphate is on the EU list of critical raw materials (European Commission 2014).

The consequence of all these developments, the short-term framing of many politicians and the long-term existence (‘generation time’) of cities (Table 1), may be perceived as a recipe for disaster. Cities require an integrated long-term framing of their plans and actions (proactive transitions) as there will not be a second chance to plan and build cities in a smart, sustainable, flexible and adaptive manner. Time is pressing, and the reality is increasingly becoming more a matter of now or never, of make or break.

3 Water governance

3.1 What is water governance?

To tackle the challenges of water in the city, it is necessary to take numerous aspects, interests and actors into account (Philip et al. 2011). These can be brought together under the heading of water governance. Hofstra (2013) considered a number of definitions. The Water Governance Centre (2012) and the OECD (2011a) have adopted the definition of the Global Water Partnership (GWP) on governance: ‘*the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society and for different purposes*’. According to the GWP, water governance covers the mechanisms, processes and institutions by which all stakeholders—government, the private sector, civil society, pressure groups—on the basis of their own competences, can contribute their ideals, express their priorities, exercise their rights, meet their obligations and negotiate their differences. Recently, the OECD (2015b) adopted the following definition of water governance: *the range of political, institutional and administrative rules, practices and processes (formal*

Table 1 Generation times for some species (modified after Van Leeuwen and Vermeire 2007)

Species	Generation time
Bacteria	≈0.1 days
Green algae (<i>Chlorella</i> sp.)	≈1 day
Water fleas (<i>Daphnia</i> sp.)	≈10 days
Snails (<i>Lymnaea</i> sp.)	≈100 days
Rats	≈1 year
Politicians	≈5 years
Man	≈25 years
Cities	>100 years

and informal) through which decisions are taken and implemented, stakeholders can articulate their interests and have their concerns considered, and decision-makers are held accountable for water management.

Driessen et al. (2012) carried out an analysis of various governance models. The authors differentiated between central, decentral, public–private and interactive governance, as well as self-governance. Lange et al. (2013) elaborated this further in a multidimensional approach in which a distinction was made between political processes (politics), institutional structures (polity) and policy content (policy). The recently published UN guidelines on water governance (UNDP 2013) set out four dimensions: the economic, social, political and ecological dimensions, in which the UNDP makes no distinction between the political and administrative dimension but combines both aspects in the political dimension.

Governance is the work of people and is all about ‘who does what?’ According to Kuijpers et al. (2013), the term actually covers three essentially different aspects, i.e.:

1. *Governing*: holding responsibility for and directing the management of a water or other system;
2. *Managing*: ensuring adequate capacity and overseeing the operation, etc. of a managed water or other system;
3. *Supervising*: exercising influence and intervening in the water or other system for the purpose of its management.

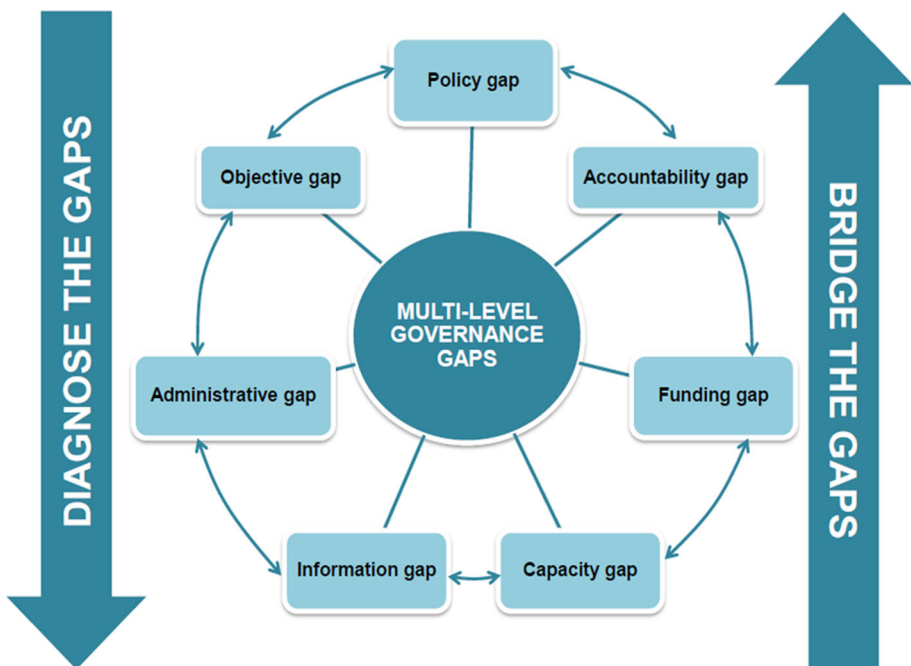


Fig. 4 OECD multi-level governance framework (OECD 2015b)

3.2 Governance gaps and capacities

An OECD study on water governance in 17 OECD countries (OECD 2011a) revealed that obstacles can be found at several levels. The OECD listed seven of them (Fig. 4). The biggest challenges, according to the OECD, are institutional fragmentation, ambiguous legislation, poor implementation of multi-layered governance, as well as matters such as limited capacity at local level, unclear allocation of roles and responsibilities, fragmented financial management and uncertain allocation of resources. Often there are also no long-term strategic plans and insufficient resources to be able to measure performance. This leads to weak accountability and little transparency. All these challenges are often rooted in inadequately coordinated goals and insufficient steering of the interactions between stakeholders, the actors in the water cycle. In short, many plans sprouting in various directions, but, all in all, they do not add up to a clearly signposted route heading in a common sustainable direction. Recently, the OECD published their principles on water governance as well as a review of water governance in 48 cities (OECD 2015b, c). One of the conclusions is that building adequate governance capacities is a premise for sustainable futures of cities (OECD 2015c).

4 Transitions

By the year 2100, the total world population is estimated at 11 billion and about 80 % will live in cities (UN 2015a). This raises questions about options we may have to make our cities more sustainable and resilient, particularly with regard to water. How can we successfully transform our cities with future generations (our children and grandchildren) in mind? Transitions are understood as multilevel, multiphase processes of structural change in societal systems; they realise themselves when the dominant structures in society (regimes) are put under pressure by external changes in society, as well as endogenous innovation (Loorbach 2010). Gleick (2003) talked about soft-path solutions. Three important considerations are raised by Loorbach (2010):

1. All societal actors exert influence and thus direct social change, being aware of the opportunities as well as the restrictions and limitations of directing;
2. Top-down planning and market dynamics only account for part of societal change; network dynamics and reflexive behaviour account for other parts;
3. Steering of societal change is a reflexive process of searching, learning and experimenting.

Examples of transition practices are provided by Loorbach and Rotmans (2010). Strategies, actors and resources are discussed by Farla et al. (2012) and Gupta et al. (2010), whereas Markard et al. (2012) provide a review on the conceptual framework of sustainability transitions. Many international organizations address these issues too (BAUM 2013; OECD 2011a, 2015a, b; European Commission 2011, 2012). Practical guidance on the governance of transitions is provided by UNDP (2013), OECD (2015b), and in training modules (Philip et al. 2011).

Frijns et al. (2013) discuss the future challenges in the Dutch water sector such as (1) unstable economy, (2) citizen centric, (3) changing demographics, (4) sustainability, (5) raw material shortages/prices, (6) NBIC convergence (the convergence and growing importance of nano, bio, information and cognitive technologies), (7) transsectoral

innovation, (8) shifts in governance, (9) the city and (10) social networks. When this is scaled up to a global approach, there will be numerous added factors, including social and cultural differences in policy formulation and, especially, in the areas of implementation and enforcement. In practical terms, how to deal with corruption and how to communicate with people who are hungry, living under appalling conditions and are still illiterate too? With no pretence to be complete, seven points for successful transitions can be brought forward:

1. Develop a shared long-term vision
2. Stakeholder participation: involve civil society, the commercial sector along with other stakeholders
3. SMART transitions with a focus on co-benefits
4. Not only technology development
5. Make data accessible and applicable
6. Carry out a thorough cost–benefit analysis and remove financial barriers
7. Monitor implementation.

4.1 Develop a shared long-term vision

Developing a long-term vision together is an important prerequisite to bring about change. This can be summarized as participative scenario planning and backcasting. This approach aims to envision a coherent future picture for the long term together with the actors/stakeholders involved and from that, by working backwards (backcasting) to arrive at a plan of action for that period (i.e. for the short term). This process begins by involving the most relevant actors (open and inclusive development), and doing so as early as possible in the process (Van Leeuwen and Vermeire 2007). There are many actors in IWRM, as described in the excellent training modules of SWITCH (Philip et al. 2011), the guide for water governance (UNDP 2013) and the OECD (2011a; 2015b).

4.2 Stakeholder participation: involve civil society, the commercial sector along with other stakeholders

Governance is a concept that has emerged in political, environmental and sustainability studies in response to a growing awareness that the authorities are no longer the only relevant actors when it comes to managing society's public affairs (Lange et al. 2013). This is reflected in the European Green City Index (2009) in Europe that was commissioned by Siemens. This index shows how sustainable European cities are. This study of 30 European cities showed a surprisingly strong correlation between the green city index and the voluntary participation index. In the notes to this report, it is also concluded that achieving the CO₂ reduction targets in London had more to do with the involvement of the people and businesses than the authorities. It provides a good example of the opportunities available for achieving ambitious goals in IWRM. The process is supported by a common interest and a 'broadly accepted' purpose among the parties involved (Kuijpers et al. 2013).

4.3 SMART transitions with a focus on co-benefits

Today, the consequences of short-term governance are particularly clear in the fragmentation of urban development and transitions. Far more coherence is needed between urban, regional and national policies (UN-Habitat 2013; OECD 2015a). According to the OECD

(2011a;2015a, b), water governance often shows many gaps (Fig. 4). In some countries, even at central level, sometimes ten or more ministries are actively concerned with water policy. This is worrying when you realize that 21 of the 33 cities which in 2015 will have more than 8 million inhabitants are along the coast (UN 2013b).

Ideally, cities should develop a cohesive set of long-term objectives that should be SMART: *Specific* (target a specific area for improvement), *Measurable* (quantify or at least suggest an indicator of progress), *Assignable* (specify who will do it), *Realistic* (state what results can realistically be achieved, given available resources), *Time-related* (specify when the result(s) can be achieved). Very often clear objectives are not set and—as a result—many cities are neither smart nor future proof. The cost of inaction (or ad hoc sectoral action) is generally very high (Economist Intelligence Unit 2015; UNEP 2013; Leonardsen 2012).

Governance of cities is never simple (Fig. 4). It is a matter of cooperation in complexity. Transparency, accountability and participation are the criteria for good governance. In the development of a long-term vision for a city with different stakeholders, there will be differences of outlook, interests, short-term and long-term perspectives, ‘generation times’, planning horizons, investments and returns. The transitions in infrastructure, in particular, need to be flexible and adaptive, because, as indicated above, the investments are huge and, in principle, must create value (Kuijpers et al. 2013). Colliding short- and long-term interests will threaten the success of the process. Long-term goals are often not served by short-term political thinking as cities have long generation times (Table 1).

Over the past 20 years, a different view of the role of government has evolved, both in government itself and in society. To an increasing degree, government sees for itself only a legislating and facilitating role. Under this new political and social philosophy,

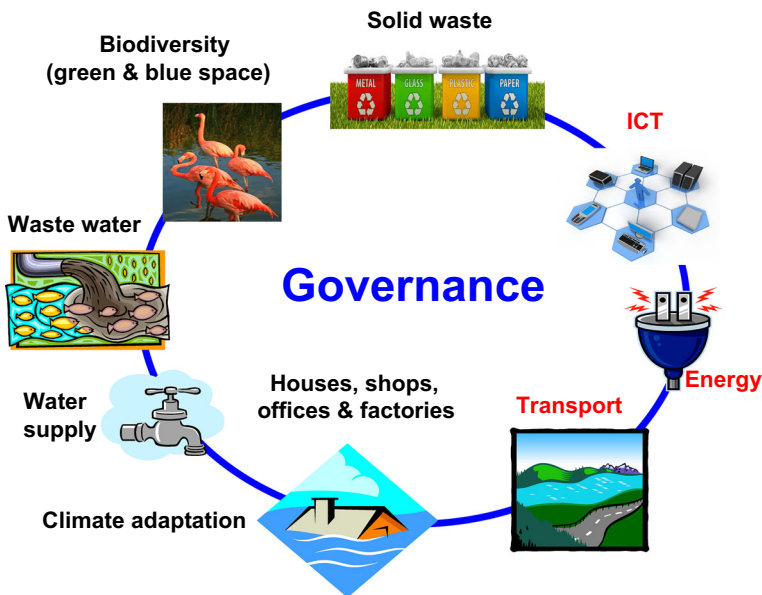


Fig. 5 Simplification of a city. The red items ICT, transport and energy are part of the EU Smart City Policy (European Commission 2013). Governance is considered to be a horizontal activity. Recently, water and waste have been included in the EU policy on smart cities (European Commission 2015c)

government is operating more at arm's length and new initiatives are increasingly being developed by society. It is said, however, that steering is necessary, but it no longer needs to be government which arranges and decides on everything (Lange et al. 2013; Kuijpers et al. 2013). All these actors, government included, need sufficient expertise at their disposal. Local stakeholder needs 'knowledge receptors' too in order to properly manage or co-manage these complex governance processes. Both the City of Amsterdam (Van Leeuwen and Sjerps 2015a, b) and Melbourne (Van Leeuwen 2015) are examples of adequate water governance at local level. The secret of Melbourne's success was the transparent governance structure that has been set up in a reaction to the 'Millennium Drought' and success has come from many organizations working together to a common goal (Van Leeuwen 2015). Amsterdam has a long tradition in water management, and its current focus is on the integration of water, energy and material flows (Van der Hoek et al. 2015).

In the development or reconstruction of cities, optimal use should be made by exploring options for win-win's or co-benefits for the different issues that need to be addressed in cities. For instance, road reconstruction can be combined with the renewal or installing of water distribution networks, sewer systems, and the creation of blue and green space. This would save a lot of time, money and nuisance for citizens (Fig. 5; Table 2). Figure 5 represents a simplified city in which nine urban sectoral agendas are shown: ICT (information and communications technology), energy and transport (European Commission 2013), solid waste, green and blue space, water supply, wastewater, climate adaptation, houses and factories. Governance is considered to be a horizontal issue linked with all other agendas in a city. At a recent public consultation, the European Commission has decided for an upgraded and more holistic Smart Cities and Communities policy to better integrate and connect energy, transport, water, waste and ICT (European Commission 2015c). From Table 2, it can be demonstrated that a smart city policy addressing only ICT, transport and energy can be considered as a maximization of missed opportunities in cities as more than 90 % of the potential interactions or win-wins between these sectoral agendas are not explored. The recent decision to include also waste and water is a step

Table 2 Illustration of the relevance of co-benefits of integration in city planning as part of a cohesive long-term strategy for cities

Policy	Number of issues (n)	Number of P. I. ^a	Issues addressed	Interactions addressed	Missed P. I.	Missed P. I. (%)
Smart cities ^b	9	36	3	3	33	92
Smart cities ^c	9	36	6	15	21	58
SMARTER cities ^d	9	36	9	36	0	0

The total number (n) of issues in cities is nine (Fig. 5). Governance is considered to be a horizontal aspect interacting with all other issues in cities

^a P. I. is the total number of potential interactions. The number of potential interactions is calculated as follows: $P. I. = \frac{1}{2}n \times (n - 1)$

^b Issues addressed are ICT, transport and energy (European Commission 2013)

^c Issues addressed are ICT, transport, energy, waste (taken as solid waste and wastewater) and water (European Commission 2015c)

^d Example of a cohesive integral Urban Agenda addressing all nine topics in a city

forward, but still many opportunities (58 %; Table 2) are not explored, including climate adaptation in cities, which is another omission. The obvious conclusion is that smarter cities need to develop a cohesive long-term plan and integrate/combine agendas as this will save time and money and better serves the needs of their taxpayers.

Often, there are governance gaps and barriers, not only for water governance (OECD 2015b, c), but also for all other urban adaptation and mitigation plans (Reckien et al. 2015), making smart long-term transitions, easier said than done. Nevertheless, inspiring examples are provided by the city of Melbourne on water and climate adaptation (Van Leeuwen 2015), by the city of Hamburg on energy efficiency and the introduction of the water cycle concept in city planning (Van Leeuwen and Bertram 2013), and by the city of Amsterdam on the integration of water, energy and material flows (Van der Hoek et al. 2015; Van Leeuwen and Sjerps 2015).

4.4 Not only technology development

The recent attention devoted to the complex issue of water governance follows a general shift in the focus on ‘technical’ infrastructure-driven solutions to demand-driven solutions which underline the role of institutions, along with economic and social processes (OECD 2011a, 2015b; Van Someren and Van Someren-Wang 2013). According to European Commissioner Hahn (BAUM 2013) *‘technology is important to implement an intelligent city concept, to create new business opportunities, to attract investments and to generate employment. But technology alone would not bring about any wonders. Good governance and the active involvement of citizens in the development of new organisation models for a new generation of services and a greener and healthier lifestyle are also important’*. At the global level, there seems to be a greater need for smart implementation of state-of-the-art technologies, i.e. communities of practice, rather than in the development of new technologies for two reasons: (1) developing countries account for 93 % of urbanization globally, 40 % of which is the expansion of slums (UN 2015b), and (2) major improvements in urban water cycle services can be obtained by cleverly combining best practices in cities as clearly demonstrated in a study of 11 municipalities and regions (Van Leeuwen 2013). Therefore, it is important to speed up implementation by investing in smart demonstration projects on water, waste and climate mitigation and adaptation with affordable and adaptive state-of-the-art technologies (CCS 2008). Good water governance is critical to manage water-related risks at an acceptable cost and in a reasonable time frame so that the next generation does not inherit liabilities and costs from either inaction or poor decisions taken today (OECD 2015c). This is the real challenge for the upcoming HABITAT III conference (UN-HABITAT 2015).

4.5 Make data accessible and applicable

Utilities in general obtain a lot of information on their water and wastewater services. One of the recommendations of the OECD (2011a) is to create, update and harmonize information systems and databases in order to share water policy at river basin, national and international levels. Most of the data for the baseline assessments (City Blueprints) of cities have been collected and provided by the cities or their utilities (Koop and Van Leeuwen 2015a, b). The collection of data is time-consuming, both for the utility and for the scientists who gather these data in order to provide baseline assessments of IWRM. Some of this knowledge is collated and held by water management actors including the utility

operators and the different levels of environmental authorities; all of which may have their own distinct reference points and definitions (EEA 2014).

Benchmarking improves performance by identifying and applying best demonstrated practices to operations and sales. The objectives of benchmarking are (1) to determine what and where improvements are called for, (2) to analyse how other organizations achieve their high-performance levels and (3) to use this information to improve performance. Benchmarking networks collect data from their members. The European Environment Agency (EEA 2014) observed that the data policies for benchmarking networks are defined by their members and that results are often presented in an aggregated or anonymous form, preventing individual plants/utilities to be identified directly. Often, the underlying data are considered confidential (EEA 2014). In order to meet the enormous water challenges as described above, this policy needs to change. Transparency and accountability are crucial for utilities, and certainly utilities paid by the taxpayers. These asymmetries of information (quantity, quality, type, scale and confidentiality) between different stakeholders are one of the key coordination gaps in (water) policy (Fig. 4). Secondly, there is the problem of scale. Given that cities are becoming increasingly important, then it is necessary to have harmonized and up-to-date data at city level (urban hydro-informatics). Applicable knowledge that is understandable for all stakeholders is necessary to enhance public engagement and well-informed decisions.

4.6 Carry out a thorough cost–benefit analysis and remove financial barriers

To start at the end: scarce financial resources need not necessarily be an obstacle. On the contrary, limited resources often inspire creativity and foster cooperation between public and private investors, as well as the involvement of civil society. Civil society underpins urban development and will strive for cost-effective operations in cities with a maximum of cost-saving options (Table 2). It is primarily all about three things: communication, involvement and ownership. The decisive factor is that through transparency, inspiring confidence and specifying the tangible benefits, private individuals will get behind a common ideal. This will enable civil society to strongly identify with the city and urban society. Ordinary people will then feel involved as individuals and support developments with their time and money (BAUM 2013). Groups of people, private institutions, societies, clubs, religious communities, charitable organizations, pressure groups, i.e. non-governmental organizations (NGOs), should not be overlooked (Philip et al. 2011). Financial limitations are therefore not always an obstacle but often provide the impetus for creative solutions because it is then necessary to look for ways to link up with other interests and solutions (Table 2). Further to which, a thorough cost–benefit analysis of various promising solutions is required. Often it turns out that these solutions are also more affordable when considered over the longer term. Institutional investors—pension funds, insurance companies and mutual funds—are able to invest in high yield, smart and sustainable infrastructures (OECD 2011b). It is therefore mainly a matter of making transparent long-term plans which will create value.

4.7 Monitor implementation

It was once said by the American delegation during the negotiations on the European REACH regulation that legislation is only as good as its implementation and enforcement. That also applies to city planning. Furthermore, continuous monitoring is necessary for learning, maintaining flexibility and securing continuous improvement.

5 City Blueprints

5.1 Results

The City Blueprint provides municipalities and regions with a practical and broad framework to define steps towards realizing a more sustainable and resilient water cycle in collaboration with key stakeholders. This assessment methodology has been applied to 45 municipalities and regions, mainly in Western Europe (Van Leeuwen et al. 2015b). Detailed reviews are available for Malmö (Mottaghi et al. 2015), Rotterdam (Van Leeuwen et al. 2012), Hamburg (Van Leeuwen and Bertram 2013), Amsterdam (Van Leeuwen and Sjerps 2015b) and Istanbul (Van Leeuwen and Sjerps 2015a). Detailed reviews of cities

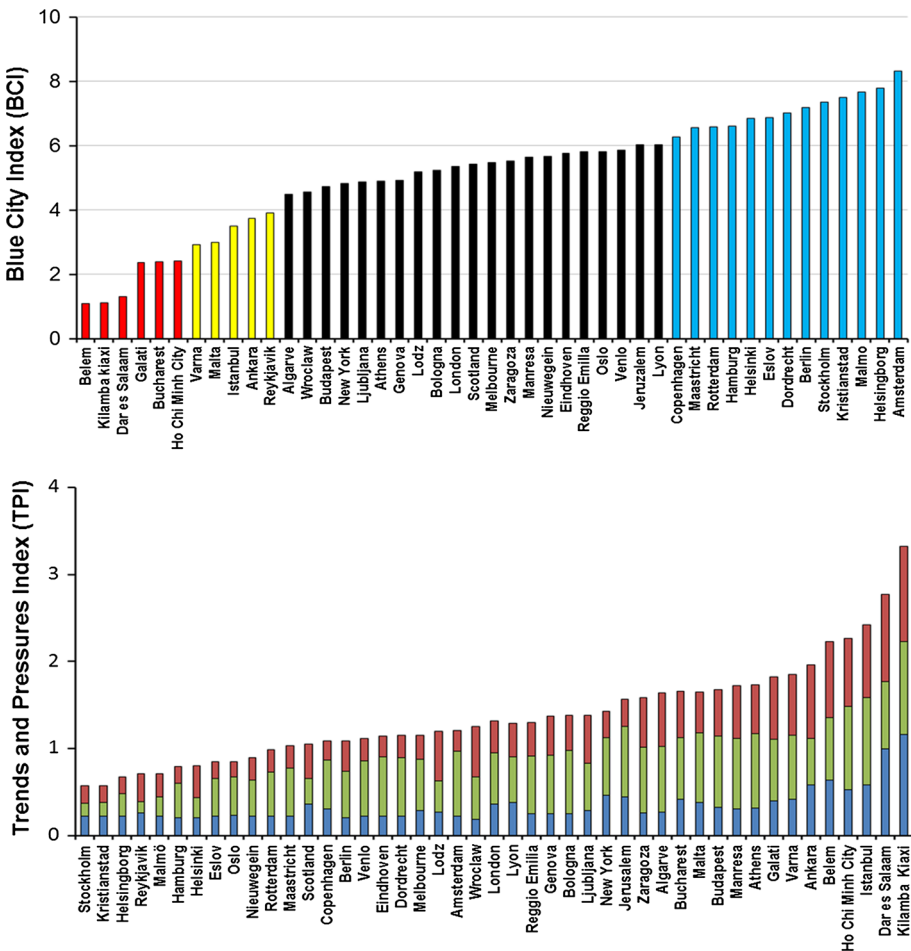


Fig. 6 Results of the City Blueprint analysis of 45 municipalities and regions in 27 different countries. *Bottom* TPI (arithmetic average of 12 indicators), where *green*, *red* and *blue* represent the share of the environmental, financial and social indicators, respectively, to the overall TPI. *Top* BCI (geometric mean of 25 indicators) of the City Blueprint according to Koop and Van Leeuwen (2015a, b, c)

outside Europe are available for Dar Es Salaam (Van Leeuwen and Chandy 2013), Ho Chi Minh City (Van Leeuwen et al. 2015a) and Melbourne (Van Leeuwen 2015).

Recently, the City Blueprint approach was critically reviewed to better separate cities' IWRM performance from general trends and pressures that can hardly be influenced directly (Koop and Van Leeuwen 2015a). The Trends and Pressures Framework (TPF) comprises indicators for social, environmental and financial classes and these indicators

Table 3 Categorization of different levels of sustainable IWRM in cities (Koop and Van Leeuwen 2015b)

IWRM category	Description
Cities lacking basic water services (BCI 0–2)	Access to potable drinking water of sufficient quality and access to sanitation facilities are insufficient. Typically, water pollution is high due to a lack of wastewater treatment (WWT). Solid waste production is relatively low but is only partially collected and, if collected, almost exclusively put in landfills. Water consumption is low, but water system leakages are high due to serious infrastructure investment deficits. Basic water services cannot be expanded or improved due to rapid urbanization. Improvements are hindered due to governance capacity and funding gaps
Wasteful cities (BCI 2–4)	Basic water services are largely met but flood risk can be high and WWT is poorly covered. Often, only primary and a small portion of secondary WWT is applied, leading to large-scale pollution. Water consumption and infrastructure leakages are high due to the lack of environmental awareness and infrastructure maintenance. Solid waste production is high, and waste is almost completely dumped in landfills. Governance is reactive, and community involvement is low
Water-efficient cities (BCI 4–6)	Cities implementing centralized, well-known, technological solutions to increase water efficiency and to control pollution. Secondary WWT coverage is high, and the share of tertiary WWT is rising. Water-efficient technologies are partially applied; infrastructure leakages are substantially reduced, but water consumption is still high. Energy recovery from WWT is relatively high, while nutrient recovery is limited. Both solid waste recycling and energy recovery are partially applied. These cities are often vulnerable to climate change, e.g. urban heat islands and drainage flooding, due to poor adaptation strategies, limited storm water separation and low green surface ratios. Governance and community involvement has improved
Resource-efficient and adaptive cities (BCI 6–8)	WWT techniques to recover energy and nutrients are often applied. Solid waste recycling and energy recovery are largely covered, whereas solid waste production has not yet been reduced. Water-efficient techniques are widely applied, and water consumption has been reduced. Climate adaptation in urban planning is applied, e.g. incorporation of green infrastructures and storm water separation. Integrative, centralized and decentralized as well as long-term planning, community involvement and sustainability initiatives are established to cope with limited resources and climate change
Water-wise cities (BCI 8–10)	There is no BCI score that is within this category so far. These cities apply full resource and energy recovery in their WWT and solid waste treatment, fully integrate water into urban planning, have multi-functional and adaptive infrastructures, and local communities promote sustainable integrated decision-making and behaviour. Cities are largely water self-sufficient, attractive, innovative and circular by applying multiple (de)centralized solutions

have 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 (Koop and Van Leeuwen 2015a). The results for 45 municipalities and regions are provided in Fig. 6.

The performance-oriented set of indicators of the City Blueprint Framework (CBF) provides a snapshot of the current IWRM performance. The Blue City Index[®] or BCI is the geometric mean of 25 indicators which varies from 0 to 10 (Koop and Van Leeuwen 2015a). The BCIs for 45 municipalities and regions are also provided in Fig. 6. The CBF consists of 25 indicators divided over the following seven categories: water quality, solid waste treatment, basic water services, wastewater treatment, infrastructure, climate robustness and governance. The indicator scores of each city are shown in a spider diagram (Koop and Van Leeuwen 2015a). The methodology is summarized in a simple brochure (Van Leeuwen and Elelman 2015), two publications (Koop and van Leeuwen 2015a, b) and in a detailed report (Koop and Van Leeuwen 2015c).

The indicator scores may facilitate sharing of knowledge, experiences and best practices between cities (Van Leeuwen 2013). The potential performance improvement (PPI) for each indicator is the maximum indicator score minus the actual score. The PPI may guide cities in their transitions towards more sustainable IWRM and innovative urban planning, leapfrogging arrangements that have locked-in many cities (Brown et al. 2009; OECD 2015a).

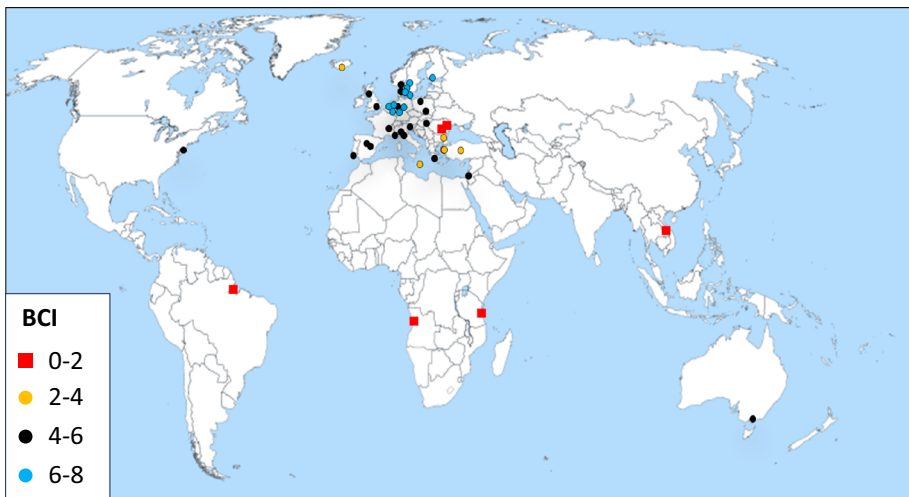


Fig. 7 Municipalities and regions assessed with the City Blueprint. Red, orange, black and blue represent municipalities and regions with a geometric BCI between 0–2 (cities lacking basic water services), 2–4 (wasteful cities), 4–6 (water-efficient cities), and 6–8 (resource-efficient and adaptive cities), respectively (Koop and Van Leeuwen 2015b). Most cities are from north-western Europe. Cities outside Europe are: Ankara and Istanbul (Turkey), Jerusalem (Israel), Kilamba Kixai (Angola), Dar es Salaam (Tanzania), Ho Chi Minh City (Vietnam), Belém (Brazil), Melbourne (Australia) and New York City (USA)

Table 4 Basic socio-economic context and IWRM performance in different world regions

	North-Western Europe [Amsterdam]	Eastern Europe and Turkey [Istanbul]	Africa [Dar es Salaam]	Australia [Melbourne]	South-east Asia [Ho Chi Minh City]	Latin America [Belem]	North America [New York]
Social economic context							
Urbanization rate (%) ^a	0.9 [1.0]	2.0 [2.0]	3.7 [5.4]	1.31 [1.6]	2.9 [2.9]	1.4 [1.2]	1.3 [1.0]
GDP (US\$ 2013/capita) ^b	58,334 [47,651]	10,777 [10,745]	2148 [690]	52,311 [64,157]	9977 [1896]	9058 [10,958]	38,645 [52,839]
Poverty rate (% pop. < 2US\$) ^c	0.4 [0.4]	1.0 [2.6]	34.4 [33.6]	1.4 [1.4]	11.9 [12.5]	3.4 [6.8]	2.2 [1.7]
Water							
Access to drinking water (%) ^d	99.9 [100.0]	99.3 [100.0]	89.1 [60.0]	100.0 [100.0]	95.5 [84.0]	97.3 [70.0]	98.7 [100.0]
Access to sanitation (% of urban pop.) ^e	98.4 [100.0]	96.0 [95.0]	47.7 [56.0]	100.0 [100.0]	88.6 [12.0]	88.9 [7.0]	96.0 [100.0]
Secondary WWT (%) ^f	85.4 [99.0]	47.8 ^g [35.0]	— [5.0]	88.0 [100.0]	— [6.0]	— [7.7]	68.3 [72.0]
Nutrient recovery (%)	45.2 ^k [100.0]	5.4 ^l [11.8]	— [0.0]	— [0.0]	— [0.0]	— [0.0]	— [72.0]
Energy recovery (%)	56.2 ^k [100.0]	39.7 ^l [2.1]	— [0.0]	— [90.0]	— [0.0]	— [0.0]	— [72.0]
Leakages (%)	12.9 ^k [5.4]	30.7 ^l [25.0]	— [30.0]	— [11.0]	— [23.0]	— [48.0]	— 8.0]
Storm water separation (%)	55.7 ^k [82.8]	47.1 ^l [70.0]	— [20.0]	— [100.0]	— [5.0]	— [30.0]	— [40.0]
Solid waste							
Solid waste collected (kg/cap/year) ^g	546.6 [600.0]	360.4 [419.0]	195.3 [365.0]	640.0 [640.0]	281.3 [296.0]	331.7 [383.2]	617.9 [730.0]
Solid waste recycled (%) ^h	29.6 [99]	11.4 [1.0]	3.0 [5.0]	30.3 [42.0]	10.2 [5.0]	5.35 [0.0]	18.0 [46.0]

Table 4 continued

	North-Western Europe [Amsterdam]	Eastern Europe and Turkey [Istanbul]	Africa [Dar es Salaam]	Australia [Melbourne]	South-east Asia [Ho Chi Minh City]	Latin America [Belem]	North America [New York]
Climate robustness							
CO ₂ emissions (metric tons per capita) ^b	8.51 [-]	5.9 [-]	0.8 [-]	11.8 [-]	2.8 [-]	2.9 [-]	11.7 [-]
Climate adaptation (-)	7.5 ^k [10]	4.5 ^l [4]	- [2]	- [8]	- [7]	- [0]	- [10]
Governance							
Management and action plans (-)	7.5 ^k [7]	5.6 ^l [5]	- [2]	- [10]	- [7]	- [0]	- [10]
Public participation (%) ^j	41.2 [44.0]	23.3 [8.0]	- [5.0]	- [44.0]	- [5.0]	- [5.0]	- [40.0]

Provided are averages for countries in these regions as well as one city, assessed with the City Blueprint approach (Koop and Van Leeuwen 2015c)

^a CIA (2014); ^b IMF (2013); ^c World Bank (2015a); ^d World Bank (2015b); ^e World Bank (2015c); ^f OECD (2013); ^g Waste Atlas (2015); ^h World Bank (2015d); ⁱ EFILWC (2012); ^j Secondary WWT of Ukraine, Moldova, Bosnia, Montenegro and Macedonia are missing and are not included in the average of Eastern Europe; ^k Average of all North-Western European cities ($n = 21$) assessed by the City Blueprint approach; ^l Average of all Eastern European cities ($n = 9$) assessed by the City Blueprint approach

5.2 Categorization of different levels of sustainability in cities

Although our City Blueprint research is focussed on the performance of IWRM in European cities, we have tried to include also other geographical regions. The selection of cities is therefore not random at all, but regionally biased towards Western Europe. With these limitations in mind, the challenges on water, waste and climate change can be discussed globally by clustering cities into distinct categories of sustainability and by providing additional data and information for various global regions. The categorization of cities is based on hierarchical clustering with the squared Euclidean distances for all 25 indicators (Koop and Van Leeuwen 2015b) and provided in Table 3.

5.3 Regional challenges

The geographical distribution of municipalities and regions and their categorization is shown in Fig. 7. Basic information on regions and cities is provided in Table 4. As stated before, the selection of cities is not random at all, but regionally biased towards Western Europe. Therefore, further research of cities in other global regions is needed. With this limitation in mind, the following general observations can be made.

- The challenges of water, waste and climate change development vary from one region to another.
- South-east Asia. Rapid population growth and rapid socio-economic changes place increasing pressure on natural resources (Dobbs et al. 2012; Green City Index 2015). Excessive water abstraction, land subsidence, decline in groundwater level, saline water intrusion and pollution can be observed in Ho Chi Minh City and many other cities in south-east Asia (Van Leeuwen et al. 2015a). This is in line with observations by UNESCO (2015a, b). Solid waste collection and recycling (Jambeck et al. 2015) as well as water infrastructure upgrading are major challenges as well (Van Leeuwen et al. 2015a).
- Africa. By 2030, the urban population in Africa and Asia will double (UNESCO 2015a). Dar es Salaam in Tanzania is among the ten fastest growing cities in the world (Green City Index 2015). Little more than half of the population in Dar es Salaam has access to some form of sanitation, but the wastewater generated by 15 % of the city residents who are connected to the sewer system is discharged into the sea untreated (Van Leeuwen and Chandy 2013). There is also no regular waste collection and many residents simply burn their rubbish (Koop and Van Leeuwen 2015c). Based on other cities assessed in Africa (Green City Index 2015), the challenges of Dar es Salaam are no exception. The security of water, food and energy are major challenges, and sustainable development is perhaps more important for Africa than other regions of the world (UNESCO 2015a).
- Australia. Melbourne is the only city in this world region that has been assessed with the City Blueprint approach (Van Leeuwen 2015). The challenges of Melbourne under a changing and uncertain climate became apparent during the ‘Millennium drought’, a decade long period of extreme dry conditions across southern Australia throughout the 2000s. Melbourne scores highly in areas such as water efficiency, wastewater efficiency, 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 storm water have recently been published. Energy efficiency of buildings, nutrient recovery (especially phosphate) from wastewater and

sewage sludge recycling are topics for improvement. The same holds for the production and proper handling of solid waste. Moreover, the emissions of GHGs in Australia are relatively high (Table 4).

- Latin America. Belém is the only city in this world region that has been assessed with the City Blueprint. Flooding is a very serious concern in Belém. Urban environmental concerns such as traffic congestion, land use policies, waste disposal and air quality are immediate concerns to the majority of Latin America's residents, simply because 81 % of the population already lives in cities (Green City Index 2015). Access to sanitation and drinking water are challenges in several cities in Latin America (UNESCO 2015a, b). According to UNESCO (2015a), a major priority for Latin America is to build the formal institutional capacity to manage water resources and bring sustainable integration of water resources management and use into socio-economic development and poverty reduction. Another priority is to ensure the full realization of the human right to water and sanitation in the context of the post-2015 development agenda. Provided that Belém is a representative sample of a city in Latin America, these observations are fully supported by the City Blueprint analysis, as the BCI of Belém is 1.1. In other words, the challenges of Belém expressed as PPI are nearly nine points.
- North America. New York is the only city in this world region that has been assessed with the City Blueprint approach. Parts of the North-American continent suffer from droughts, whereas in 2012, New York suffered from hurricane Sandy. 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). The USA emits double the average amount of GHGs, while their BCI is about average (World Bank 2015d; Koop and Van Leeuwen 2015c). New York is vulnerable to extreme weather because the urban soil is largely sealed with impermeable concrete, asphalt and stone (NYC 2010). Rainwater can hardly infiltrate and forms large amounts of runoff which may result in urban drainage flooding and amplifies the impact of extreme weather which happened in 2012. Furthermore, New York produces a lot of solid waste and can improve on solid waste recycling, sewage sludge recycling, sewer maintenance and green space (Koop and Van Leeuwen 2015c). UNESCO (2015a) concludes that increasing resource use efficiency, reducing waste and pollution, influencing consumption patterns and choosing appropriate technologies are the main challenges facing both Europe and North America.
- Europe. The only continent for which an adequate number of municipalities and regions have been assessed using the City Blueprint shows a high variation in IWRM performance (Figs. 6, 7; Table 4). The differences between Western and Eastern Europe is striking, part of which can be explained by non-existing, badly maintained or outdated water infrastructure and technology in Eastern Europe. The overall conclusion of UNESCO (2015a) as quoted for North America also holds for Europe. Upgrading and renewing existing infrastructures remain a challenge and are illustrated by the high leakage rates (> 40 %) in some European cities and fully support the conclusions of the OECD (2015a).
- Until now, none of the cities can be categorized as water-wise cities (Koop and Van Leeuwen 2015a, b).

Our research shows that cities with a high BCI are those cities with high ambitions to improve IWRM, with an active civil society (involvement in voluntary work), in countries with greater prosperity (high GDP) and high governmental effectiveness (Koop and Van Leeuwen 2015b). Similar conclusions have been provided by Reckien et al. (2015) in an empirical analysis of urban adaptation and mitigation plans in European cities. Our work is mainly based on an analysis of European cities. There is a great need to assess more cities, especially in other world regions, as a starting point for sustainability transitions and to monitor their progress on the implementation of the Sustainable Development Goals for better urban futures (UN-Habitat 2015).

6 City-to-city learning

Our work on City Blueprints shows that results can be used for a variety of purposes to:

- Aid in the evaluation and compare outcomes with other cities;
- Translate knowledge and educate;
- Raise/improve awareness (particularly in communicating with the public);
- Enable informed decision-making, i.e. stimulate proactive transitions;
- Refine parts of the assessment, with tailor-made in-depth studies and advanced models, if necessary;
- Monitor progress;
- Stimulate the exchange of best practices (Koop et al. 2015).

An important result from our work is that the wide variation in the way cities deal with their water, wastewater, solid waste and climate adaptation offers key insights for improving their resilience and sustainability, provided that cities share their best practices (Van Leeuwen 2013; Frijns et al. 2013). Theoretically, if cities would share their best practices, the BCI can reach a maximum value of 10 (Van Leeuwen 2013). It also shows that cities that currently perform well can still improve. Of course, this is ultimately the responsibility of the cities themselves. These challenges are too often not taken up, because people are waiting for new technological breakthroughs and fail to make use of existing knowledge and technologies. Therefore, we have three recommendations:

1. Cities require a long-term framing of their sectoral challenges into a proactive and coherent Urban Agenda to maximize the co-benefits and to minimize their cost.
2. Cities are encouraged to participate in learning alliances to actively share knowledge and experiences on implementation of state-of-the-art technologies (city-to-city learning). This is the most efficient way to improve IWRM (Van Leeuwen 2013; Koop and Van Leeuwen 2015b). Recently, a compendium of best practices has been completed that can help cities to choose among options to improve their performance on water, waste and climate adaptation (Koop et al. 2015).
3. Given the megatrends and water challenges in cities, existing technologies and innovations should be better embedded in urban planning. This is mainly a governance challenge (OECD 2015a). As developing countries account for 93 % of urbanization globally, 40 % of which is the expansion of slums (UNESCO 2015a), new affordable technologies need to be developed. These new and efficient technologies can gradually be introduced in the transition process allowing these cities to leapfrog towards water-wise cities.

7 Concluding remarks

It has been attempted to shed light on growth and the limits to growth, with particular emphasis on water. Freshwater scarcity is a major challenge (FAO 2011b; UNEP 2012, 2013; World Economic Forum 2014; UNESCO 2015a). The UN (2012) estimates that in 2025 about 2 billion people will have an absolute water shortage and that two-thirds of the world population will be affected by water scarcity. Estimates for 2030 assume 40 % more demand for water than is actually available (2030 Water Resources Group 2009). It means that the window we have for solutions is narrow and rapidly closing.

In the Netherlands, excellent drinking water is readily available by turning on a tap and safety is provided by the Delta Programme, while the history of that too lies in the flood disaster of 1953. Water safety and water security are not a matter of course. Actually, there is not a water crisis but a water governance crisis which now and in the very near future will become manifest in cities (OECD 2011a; Engel et al. 2011; European Commission 2011, 2015b). The solutions must also come from cities. Cities, as global change makers, must make the difference. And they can too, because there are already many good initiatives (C40Cities 2015; Philip et al. 2011; World Future Council 2014).

According to the European Commission (2013), *smart* cities are cities that focus on ICT, energy and transport. This definition was recently broadened to include water and waste (European Commission 2015a). Unfortunately, the proposed policy is still not cohesive, but fragmented and will lead to many missed opportunities for cities that are lost in sectoral agenda's and mists of techno-optimism. With the urgency of the water governance crisis, it is time that we cannot afford to lose. The European Commission can take the lead in the development of a practical coherent long-term European Urban Agenda, e.g. an EUA-2050, with cities and based on the needs of cities (European Commission 2015a, c). Such an initiative may also lead to improved visibility and a better image of Europe for the European citizens, which is a political priority for Europe. An Urban Agenda is even more needed in the rest of the world, where the challenges of water, waste and climate change are much greater than in Europe (Fig. 7; Table 4). There is a need to move towards *smarter* cities:

- *Smarter cities* are cities with a coherent long-term social, economic and ecological agenda.
- *Smarter cities* are water-wise cities that integrate their sectoral agendas on water, wastewater, energy, solid waste, transport, ICT, climate adaptation and nature into a forward-looking, coherent Urban Agenda to maximize co-benefits and to minimize the cost.
- *Smarter cities* implement a circular economy (EMF 2014, 2015a; European Commission 2015b), focus on social innovation (Science Communication Unit 2014) and, last but not least, greatly improve on governance (OECD 2011a, 2015a, b).

Inaction can be overcome by setting up learning alliances of cities. Globally, we need regional platforms to exchange challenges, policies and best practices between cities. International organizations (e.g. OECD, UN, WHO, FAO, and the European Commission), the scientific community, the private sector, utilities (e.g. transport, water, waste, energy and telecom utilities), the civil society, city planners, architects, coordination providers, and last but not least, all the mayors in the world, are in a remarkably privileged position to contribute to the solutions of these urgent challenges in our cities.

Water utilities have much expertise and an extensive water consumers network. There are many opportunities for the water sector as a whole and the drinking water sector in particular, but under a number of conditions which can be summarized as the three Rs: 'Reframe, Refocus, Radically'.

1. *Reframe*. The Netherlands' drinking water sector has achieved a great deal but is faced by challenges such as salinization and groundwater depletion. There are also promising opportunities for nutrient recovery and energy conservation and production (Morée et al. 2013; Frijns et al. 2012). Nevertheless, water challenges require a broader framing as water is more than just drinking water (Van Oel et al. 2009; Van Someren and Van Someren-Wang 2013).
2. *Refocus*. In view of the declining level of government involvement, there will be major opportunities for initiatives launched by civil society and the private sector. Participative scenario development and the implementation of sustainability processes in the city—a highly complex environment—make it necessary that the focus be placed primarily on governance. The extensive expertise of the technology and drinking water sectors will be vital for this. But success will not be achieved by looking to technology alone (European Commission 2011; OECD 2011a, 2015a, b; BAUM 2013).
3. *Radically*. It has been attempted here to give an impression of the speed at which global change is taking place, both economically and ecologically. The challenges are high: urbanization at a rate of 190,000 people per day, the shift in the labour market (e.g. the exodus of businesses and employment from Europe), and the safety of cities in relation to climate change and water security (World Economic Forum 2014; UNESCO 2015a). The same holds for the challenges of irrigation, i.e. food security (UNEP 2007, 2012; FAO 2011b). This together with the high costs for water infrastructure and its maintenance make water a high priority, where procrastination, i.e. the avoidance of doing tasks which need to be accomplished, will not do (UNEP 2013; Cashman and Ashley 2008; UN University 2013). Mahatma Gandhi has raised this too: '*The difference between what we do and what we are capable of doing would suffice to solve most of the world's problems*'.

Acknowledgments This paper provides a broad overview of water, waste and climate change in cities. It is an update of a previous paper on water in the city at the University of Utrecht (Van Leeuwen 2014). Our work has been financed by KWR Watercycle Research Institute in the context of Watershare[®]: sharing knowledge in the water sector (<http://www.watershare.eu/>). It is a contribution to the European Innovation Partnership on Water of the European Commission and more specifically to the City Blueprint Action Group (European Commission 2015b), coordinated by both Dr. Richard Elelman of Fundació CTM Centre Tecnològic and NETWERC H2O and Prof. Dr. C.J. van Leeuwen (KWR Watercycle Research Institute). The authors would like to thank Prof. dr. Wim van Viersen, Prof. dr. Annemarie van Wezel, Ir. MBA Idsart Dijkstra and Ir. Jos Frijns (KWR Watercycle Research Institute, the Netherlands), as well as Prof. Dr. Peter Driessen (Utrecht University, the Netherlands) for their practical and stimulating contributions. Last but not least, we would like to thank Richard Elelman, the members of the City Blueprint Action Group, and all partners of the EU BlueSCities project and all cities involved, for their dedication, voluntary contributions and discussions related to the work described in this manuscript. The European Commission is acknowledged for funding TRUST in the 7th Framework Programme under Grant Agreement No. 265122 and for BlueSCities in H2020-Water under Grant Agreement No. 642354.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

- Amundsen, H., Berglund, F., & Westskog, F. (2010). Overcoming barriers to climate change adaptation—A question of multilevel governance? *Environment and Planning C: Government and Policy*, 28, 276–289.
- Atelier Istanbul. (2012). <http://vimeo.com/41973779>. Accessed September 15, 2014.
- Bai, X. (2007). Industrial ecology and the global impacts of cities. *Journal of Industrial Ecology*, 11, 1–6.
- BAUM. (2013). *Intelligent cities: Routes to a sustainable, efficient and livable city*. Hamburg: Bundesdeutscher Arbeitskreis für Umweltbewusstes Management.
- Brown, R. R., Keath, N., & Wong, T. H. F. (2009). Urban water management in cities, historical, current and future regimes. *Water Science and Technology*, 59, 847–855.
- C40Cities. (2015). *Powering climate action: Cities as global changemakers*. London: C40 Cities.
- Cashman, A., & Ashley, R. (2008). Costing the long-term demand for water sector infrastructure. *Foresight*, 10(3), 9–26.
- CCS. (2008). *The European carbon dioxide capture and storage (ccs) project network*. https://ec.europa.eu/energy/sites/ener/files/documents/ccs_project_network_booklet.pdf. Accessed December 15, 2015.
- CEFIC. (2014). *Facts and figures 2014*. Brussels: The European Chemical Industry Council.
- CIA Central Intelligence Agency. (2014). The world factbook. *Urbanization*. <https://www.cia.gov/library/publications/the-world-factbook/fields/2212.html>. Accessed December 21, 2015.
- Delta programme. (2013). <http://www.rijksoverheid.nl/onderwerpen/deltaprogramma>. Accessed September 15, 2013, in Dutch.
- Derraik, J. G. B. (2002). The pollution of the marine environment by plastic debris: A review. *Marine Pollution Bulletin*, 44, 842–852.
- Dobbs, R., Remes, J., Manyika, J., Roxburgh, C., Smit, S., & Schaar, F. (2012). *Urban world: Cities and the rise of the consuming class*. Washington, DC: McKinsey Global Institute.
- Dobbs, R., Smit, S., Remes, J., Manyika, J., Roxburgh, C., & Restrepo, A. (2011). *Urban world: Mapping the economic power of cities*. Washington, DC: McKinsey Global Institute.
- Doughty, M., & Hammond, G. (2004). Sustainability and the built environment at and beyond the city scale. *Building and Environment*, 39(10), 1223–1233.
- Driessen, P. P. J., Dieperink, C., Van Laerhoven, F., Runhaar, H. A. C., & Vermeulen, W. J. V. (2012). Towards a conceptual framework for the study of shifts in modes of environmental governance—Experiences from the Netherlands. *Environmental Policy and Governance*, 22, 143–160.
- Economist Intelligence Unit. (2015). *The cost of inaction: recognizing the value at risk from climate change*. London: The Business Intelligence Unit. The Economist. <http://www.economistinsights.com/financial-services/analysis/cost-inaction>. Accessed October 18, 2015.
- EEA. (2007). Climate change: the costs of inaction and the costs of adaptation. Technical report No 13/2007. Copenhagen: European Environment Agency.
- EEA. (2012). *Urban adaptation to climate change in Europe: Challenges and opportunities for cities together with supportive national and European Policies*. (EEA Report 2/2012). Copenhagen: European Environment Agency.
- EEA. (2013). *Recycling rates in Europe*. Copenhagen: European Environment Agency. http://www.eea.europa.eu/about-us/what/public-events/competitions/waste-smart-competition/recycling-rates-in-europe/image_view_fullscreen. Accessed December 15, 2015.
- EEA. (2014). Performance of water utilities beyond compliance. Sharing knowledge bases to support environmental and resource-efficiency policies and technical improvements. EEA Technical report No 5/2014. Copenhagen: European Environment Agency.
- EFILWC. (2012). *Quality of life in Europe: Impact of the crisis*. Luxembourg: European foundation for the improvement of living and working conditions.
- EMF. (2014). *Towards the Circular Economy vol.3: accelerating the scale-up across global supply chains*. Ellen MacArthur Foundation. <http://www.ellenmacarthurfoundation.org/business/reports/ce2012>. Accessed June 2, 2014.
- EMF. (2015a). *Towards a circular economy. Business rationale for an accelerated transition*. Ellen MacArthur Foundation. http://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf. Accessed December 15, 2015.
- EMF. (2015b). *Growth within: a circular economy vision for a competitive Europe*. Ellen MacArthur Foundation. <http://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe>. Accessed December 15, 2015.
- Engel, K., Jokiel, D., Kraljevic, A., Geiger, M., & Smith, K. (2011). *Big cities: Big water: Big challenges: Water in an urbanizing world*. Berlin: World Wildlife Fund.

- European Commission. (2011). *Cities of Tomorrow. Challenges, vision, ways forward*. European Union. Regional Policy. Brussels: European Commission.
- European Commission. (2012). *Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. A blueprint to safeguard Europe's water resources. COM (2012)673 final*.
- European Commission. (2013). *European innovation partnership on smart cities and communities: Strategic implementation plan*. Brussels: European Commission.
- European Commission. (2014). The European critical raw materials review. MEMO/14/377 26/05/2014. Brussels. http://europa.eu/rapid/press-release_MEMO-14-377_en.htm. Accessed June 2, 2014.
- European Commission. (2015a). European innovation partnership on water. City blueprints action group, Brussels, Belgium. http://www.eip-water.eu/City_Blueprints. Accessed June 30, 2015.
- European Commission. (2015b). *Closing the loop—An EU action plan for the Circular Economy*. Brussels, Belgium. http://ec.europa.eu/priorities/jobs-growth-investment/circular-economy/docs/communication-action-plan-for-circular-economy_en.pdf. Accessed December 17, 2015.
- European Commission. (2015c). *Results of the public consultation on the key features of an EU Urban Agenda. SWD(2015) 109 final/2*. Brussels. http://ec.europa.eu/regional_policy/en/conferences/cities-2015/. Accessed September 30, 2015.
- European green city index. (2009). *Assessing the environmental impact of Europe's major cities*. Siemens: A research project conducted by the Economist Intelligence Unit.
- FAO. (2011a). *Global food losses and food waste—Extent, causes and prevention*. Rome: The Food and Agriculture Organization of the United Nations.
- FAO. (2011b). *The state of the world's land and water resources for food and agriculture: Managing systems at risk*. Rome: The Food and Agriculture Organization of the United Nations.
- Farla, J., Markard, J., Raven, R., & Coenen, L. (2012). Sustainability transitions in the making: A closer look at actors, strategies and resources. *Technological Forecasting and Social Change*, 79(6), 991–998.
- Francis, H. F. (2015). *Encyclical letter LAUDATO SI' of the Holy Father Francis on care for our common home*. Rome: Vatican Press. http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_encyclica-laudato-si.html. Accessed December 17, 2015.
- Frijns, J., Büscher, C., Segrave, A., & Van der Zouwen, M. (2013). Dealing with future challenges: A social learning alliance in the Dutch water sector. *Water Policy*, 15, 212–222.
- Frijns, J., Middleton, R., Uijterlinde, C., & Wheale, G. (2012). Energy efficiency in the European water industry: Learning from best practices. *Journal of Water and Climate Change*, 3(1), 11–17.
- Gleick, P. H. (2003). Global freshwater resources: soft-path solutions for the 21st century. *Science*, 302, 1524–1528.
- Green City Index. (2015). <http://www.siemens.com/entry/cc/en/greencityindex.htm>. Accessed December 10, 2015.
- Grant, S. B., Saphores, J. D., Feldman, D. L., Hamilton, A. J., Fletcher, T. D., Cook, P. L. M., et al. (2012). Taking the “waste” out of “wastewater” for human water security and ecosystem sustainability. *Science*, 337, 681–686.
- Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, 319, 756–760.
- Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., & Bergsma, E. (2010). The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy*, 13(6), 459–471.
- Hesketh, T., Lu, L., & Xing, Z. W. (2005). The effect of China's one-child family policy after 25 years. *New England Journal of Medicine*, 353(11), 1171–1176.
- Hoekstra, A. Y. (2014). Water for animal products: A blind spot in water policy. *Environmental Research Letters*, 9, 091003.
- Hoekstra, A. Y., Mekonnen, M. M., Chapagain, A. K., Mathews, R. E., & Richter, B. D. (2012). Global monthly water scarcity: Blue water footprints versus blue water availability. *PLoS ONE*, 7(2), e32688. doi:10.1371/journal.pone.0032688.
- Hoekstra, A. Y., & Wiedman, T. O. (2014). Humanity's unsustainable environmental footprint. *Science*, 344(6188), 1114–1117.
- Hofstra, M. (2013). Water governance, a framework for better communication. *Water Governance*, 1, 9–13.
- Hunger, M., & Döll, P. (2008). Value of river discharge data for global-scale hydrological modeling. *Hydrology and Earth Systems Science*, 12(3), 841–861.
- IMF International Monetary Fund (2013). <http://www.imf.org/external/pubs/ft/weo/2013/01/weodata/weoselco.aspx?g=2001&sg=All+countries>. Accessed December 21, 2015.

- IPCC. (2006). *CH₄ emissions from solid waste disposal. Background paper expert group CH₄ emissions from solid waste disposal*. Geneva: Intergovernmental Panel on Climate Change http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_1_CH4_Solid_Waste.pdf. Accessed December 21, 2015.
- Jalava, M., Kumm, M., Pokka, M., Siebert, S., & Varis, O. (2014). Diet change—A solution to reduce water use? *Environmental Research Letters*, *9*, 074016.
- Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., et al. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*, 768–771.
- Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J. C. J. H., Mechler, R., Botzen, W. J. W., et al. (2014). Increasing stress on disaster-risk finance due to large floods. *Nature Climate Change*, *4*, 264–268.
- Klein Goldewijk, K., Beusen, A., & Janssen, P. (2010). Long-term dynamic modeling of global population and built-up area in a spatially explicit way: HYDE 3.1. *The Holocene*, *20*(4), 565–573.
- Koop, S. H. A., & Van Leeuwen, C. J. (2015a). Assessment of the sustainability of water resources management: A critical review of the City Blueprint approach. *Water Resources Management*, *29*(15), 5649–5670.
- Koop, S. H. A., & Van Leeuwen, C. J. (2015b). Application of the improved City Blueprint framework in 45 municipalities and regions. *Water Resources Management*, *29*(13), 4629–4647.
- Koop, S. H. A. & Van Leeuwen, C. J. (2015c). *Towards sustainable water resources management: Improving the city blueprint framework*. Report KWR 2015.025. KWR Watercycle Research Institute, Nieuwegein, the Netherlands. http://www.eip-water.eu/City_Blueprints. Accessed August 7, 2015.
- Koop, S., Van Leeuwen, K., Bredimas, A., Arnold, M., Makropoulos, M. & Clarens, F. (2015). *Compendium of best practices for water, waste water, solid waste and climate adaptation*. http://www.bluescities.eu/wp-content/uploads/2015/12/D2_3_Formatted_v7.pdf. Accessed December 16, 2015.
- Kuijpers, C., Nap, R., & de Bruijn, P. (2013). Good governance in local groundwater management. By coincidence or not? *Water Governance*, *1*, 19–26. (in Dutch).
- Lange, P., Driessen, P. P. J., Sauer, A., Bornemann, B., & Burger, B. (2013). Governing towards sustainability—Conceptualizing modes of Governance. *Journal of Environmental Policy & Planning*, *15*(3), 403–425.
- Leonardsen, L. (2012). *Financing adaptation in Copenhagen*. http://resilient-cities.iclei.org/fileadmin/sites/resilient-cities/files/Webinar_Series/Webinar_Presentations/Leonardsen_financing_adaptation_in_Copenhagen_ICLEI_sept_2012.pdf. Accessed May 12, 2015.
- Ligtvoet, W., Hilderink, H., Bouwman, A., Puijenbroek, P., Lucas, P., & Witmer, M. (2014). *Towards a world of cities in 2050. An outlook on water-related challenges. Background report to the UN-Habitat Global Report*. Bilthoven: Netherlands Environmental Assessment Agency.
- Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., & Searchinger, T. (2013). *Reducing Food Loss and Waste. Working Paper, Installment 2 of Creating a Sustainable Food Future*. Washington, DC: World Resources Institute. <http://www.worldresourcesreport.org>.
- Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance*, *23*, 161–183.
- Loorbach, D., & Rotmans, J. (2010). The practice of transition management: Examples and lessons from four distinct cases. *Futures*, *42*, 237–246.
- Manfredi, S., Tonini, D., Christensen, T. H., & Scharff, H. (2009). Landfilling of waste: Accounting of greenhouse gases and global warming contributions. *Waste Management and Research*, *27*(8), 825–836.
- Mani, T., Hauk, A., Walter, U., & Burkhardt-Holm, P. (2015). Microplastics profile along the Rhine river. *Scientific Reports*, doi: [10.1038/srep17988](https://doi.org/10.1038/srep17988).
- Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*, 955–967.
- McFedries, R. (2012). Littered with ‘plastic soup’. <http://worldmaritimeneeds.com/archives/141427/%EF%BF%BClittered-with-plastic-soup/>. Accessed December 15, 2015.
- McKinsey. (2013). *Infrastructure productivity: How to save \$1 trillion a year*. London: McKinsey & Company.
- Molenaar, A., Aerts, J., Dircke, P., & Ikert, M. (2015). *Connecting Delta Cities: Resilient cities and climate adaptation strategies*. Rotterdam: Connecting Delta Cities.
- Morée, A. L., Beusen, A. H. W., Bouwman, A. F., & Willems, W. J. (2013). Exploring global nitrogen and phosphorus flows in urban wastes during the twentieth century. *Global Biogeochemistry Cycles*, *27*(3), 836–846.
- Mottaghi, M., Aspegren, H., & Jönsson, K. (2015). The necessity for re-thinking the way we plan our cities with the focus on Malmö/Towards urban-planning based urban runoff management. *Vatten*, *2015*(1), 37–43.

- NYC. (2010). City of New York: NYC green infrastructure plan. A sustainable strategy for clean waterways. http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml. Accessed March 25, 2015.
- OECD. (2011a). *Water governance in OECD countries: A multi-level approach*. Paris: Organization for Economic Cooperation and Development.
- OECD. (2011b). *International Futures Programme Pension funds investment in infrastructure. A survey*. Paris: Organization for Economic Cooperation and Development.
- OECD. (2013). Environment at a glance 2013. OECD indicators. OECD Publishing. Paris: Organisation for Economic Co-operation and Development. doi:10.1787/9789264185715-en. http://www.oecd-ilibrary.org/environment/environment-at-a-glance-2013_9789264185715-en. Accessed April 7, 2015.
- OECD. (2015a). *Water and cities: Ensuring sustainable futures*. Paris: Organisation for Economic Co-operation and Development.
- OECD. (2015b). *OECD Principles on water governance*. Paris: Organisation for Economic Cooperation and Development.
- OECD. (2015c). *Water Governance in Cities: GOV/RDPC* (2015)17. Paris: Organisation for Economic Cooperation and Development.
- Philip, R., Anton, B., & van der Steen, P. (2011). *SWITCH training kit. Integrated urban water management in the city of the future. Module 1. Strategic planning*, ICLEI, Freiburg. <http://www.switchtraining.eu/>. Accessed May 15, 2013.
- Reckien, D., Flacke, J., Olazabal, M., & Heidrich, O. (2015). The Influence of drivers and barriers on urban adaptation and mitigation plans—An empirical analysis of European cities. *PLoS ONE*, 10(8), e0135597. doi:10.1371/journal.pone.0135597.
- Richter, B. D., Abell, D., Bacha, E., Brauman, K., Calos, S., Cohn, A., et al. (2013). Tapped out: How can cities secure their water future? *Water Policy*, 15, 335–363.
- Schwarzenbach, R. P., Escher, B. I., Fenner, K., Hofstetter, T. B., Johnson, C. A., Von Gunten, U., & Wehrli, B. (2006). The challenge of micropollutants in aquatic systems. *Science*, 313, 1072–1077.
- Science Communication Unit (2014). *Science for Environment Policy. In-depth Report: Social Innovation and the Environment*. Report produced for the European Commission DG Environment. Bristol: University of the West of England.
- SDEWES. (2015). *The Sustainable Development of Energy, Water, and Environment Systems (SDEWES) Index*. Zagreb: International Centre for Sustainable Development of Energy, Water and Environment Systems. http://www.sdewes.org/sdewes_index.php. Accessed December 15, 2015.
- Toro, R. (2013). *Hurricane Sandy's impact*. <http://www.livescience.com/40774-hurricane-sandy-s-impact-infographic.html>. Accessed March 24, 2015.
- UN. (2012). *World urbanization prospects: The 2011 revision*. New York: United Nations.
- UN. (2013a). *Sustainable cities. Facts and figures*. <http://www.un.org/en/sustainablefuture/cities.asp>. Accessed October 15, 2015.
- UN. (2013b). *Disaster-resilient societies*. <http://www.un.org/en/sustainablefuture/disasters.asp>. Accessed October 15, 2015.
- UN. (2014). *The United Nations world water development report. Water and energy* Vol. 1. New York: United Nations Development Programme.
- UN. (2015a). *World urbanization prospects: The 2015 revision*. New York: United Nations.
- UN. (2015b). *The United Nations world water development report 2015: Water for a sustainable world*. Paris: UNESCO.
- UN University. (2013). *Catalyzing water for sustainable development and growth. Framing water within the post development agenda: Options and considerations*. Hamilton: United Nations University Institute for Water, Environment and Health.
- UNDP. (2013). *User's guide on assessing water governance*. Oslo: United Nations Development Programme.
- UNEP. (2007). *Fourth Global Environment outlook: Environment for development*. Geneva: United Nations Environment Programme.
- UNEP. (2012). *Fifth global environment outlook: Environment for development*. Geneva: United Nations Environment Programme.
- UNEP (2013). *City-level decoupling: Urban resource flows and the governance of infrastructure transitions. A report of the working group on cities of the International Resource Panel*. Swilling M., Robinson B., Marvin S., & Hodson, M. Nairobi: United Nations Environment Programme.
- UNESCO. (2015a). *The United Nations world water development report Water for a sustainable world*. Paris: United Nations Educational, Scientific and Cultural Organization.
- UNESCO. (2015b). *Facing the Challenges*. Paris: United Nations World Water Assessment Programme, United Nations Educational, Scientific and Cultural Organization.

- UN-Habitat. (2010). *Solid waste management in the world's cities*. London: United Nations Human Settlements Programme.
- UN-Habitat. (2013). *The state of European cities in transition. Taking stock after 20 years of reform*. Nairobi: United Nations Settlement Programme.
- UN-Habitat. (2015). <http://unhabitat.org/habitat-iii-conference/>. Accessed December 16, 2015.
- Van der Hoek, J. P., Struiker, A., & De Danschutter, J. E. M. (2015). Amsterdam as a sustainable European metropolis: Integration of water, energy and material flows. *Urban Water Journal*. doi:10.1080/1573062X.2015.1076858.
- Van Leeuwen, C. J. (2008). The China environment yearbook 2005. Book review. *Environmental Science and Pollution Research*, 15, 354–356.
- Van Leeuwen, C. J. (2013). City Blueprints: Baseline assessment of sustainable water management in 11 cities of the future. *Water Resources Management*, 27, 5191–5206.
- Van Leeuwen, K. (2014). *Water in the city: Inauguration speech*. Utrecht: University of Utrecht Faculty geosciences. (in Dutch).
- Van Leeuwen, C. J. (2015). Water governance and the quality of water services in the city of Melbourne. *Urban Water Journal*. doi: 10.1080/1573062X.2015.
- Van Leeuwen, C. J., & Bertram, N. P. (2013). Baseline assessment and best practices in urban water cycle services in the city of Hamburg. *Bluefacts. International Journal of Water Management* 2013,10–16. <http://www.bluefacts-magazin.de/heftarchiv/2013/>.
- Van Leeuwen, C. J., & Chandy, P. C. (2013). The City Blueprint: Experiences with the implementation of 24 indicators to assess the sustainability of the urban water cycle. *Water Science and Technology. Water Supply*, 13(3), 769–781.
- Van Leeuwen, C. J., Dan, N. P., & Dieperink, C. (2015a). The challenges of water governance in Ho Chi Minh City. *Integrated Environmental Assessment and Management*. doi:10.1002/ieam.1664.
- Van Leeuwen, C. J., & Elelman, R. (2015). E-Brochure of the City Blueprint. Available at: http://www.eip-water.eu/City_Blueprints.
- Van Leeuwen, C. J., Frijns, J., Van Wezel, A., & Van De Ven, F. H. M. (2012). City blueprints: 24 indicators to assess the sustainability of the urban water cycle. *Water Resources Management*, 26, 2177–2197.
- Van Leeuwen, C. J., Koop, S. H. A., & Sjerps, R. M. A. (2015b). City Blueprints: Baseline assessments of water management and climate change in 45 cities. *Environment, Development and Sustainability*. doi:10.1007/s10668-015-9691-5.
- Van Leeuwen, C. J., & Sjerps, R. M. A. (2015a). The City Blueprint of Amsterdam. An assessment of integrated water resources management in the capital of the Netherlands. *Water Science and Technology Water Supply*, 15(2), 404–410.
- Van Leeuwen, K., & Sjerps, R. (2015b). Istanbul: The challenges of integrated water resources management in Europa's Megacity. *Environment, Development and Sustainability*. doi:10.1007/s10668-015-9636-z.
- Van Leeuwen, C. J., & Vermeire, T. G. (Eds.). (2007). *Risk assessment of chemicals. An introduction* (2nd ed.). Dordrecht: Springer Publishers.
- Van Oel, P. R., Mekonnen, M. M., & Hoekstra, A. Y. (2009). The external water footprint of the Netherlands: geographically-explicit quantification and impact assessment. *Ecological Economics*, 69(1), 82–92.
- Van Someren, T. C. R. & Van Someren-Wang, S. (2013). *Strategic innovation: the creation of the water companies of the future*. 65e Vakantiecursus Drinkwater en Afvalwater. Delft: Technical University Delft.
- Van Wezel, A., Caris, I., & Kools, S. A. E. (2015). Release of primary microplastics from consumer products to wastewater in The Netherlands. *Environmental Toxicology and Chemistry*,. doi:10.1002/etc.3316.
- VROM. (2001). *General policy on waste. Fact sheet. The Hague: Ministry of Housing, Spatial Planning and the Environment*. <http://www.wbcsdcement.org/pdf/tf2/01GenPolonWaste.pdf>. Accessed December 14, 2015.
- Waste Atlas. (2015). <http://www.atlas.d-waste.com/>. Accessed December 20, 2015.
- Waste Framework Directive. (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*. Brussels: EUR-Lex—32008L0098—EN.
- Water Resources Group. (2009). *Charting our water future*. West Perth, USA: Economic framework to inform decisionmaking.
- WHO. (2008). *Safer water, better health: Costs, benefits and sustainability of interventions to protect and promote health*. Geneva: World Health Organization.

- World Bank. (2015a). Poverty gap at \$2 a day (PPP) (%). <http://data.worldbank.org/indicator/SI.POV.GAP2/countries/1W?display=default>. Accessed December 21, 2015.
- World Bank. (2015b). Improved water source, urban (% of urban population with access). <http://data.worldbank.org/indicator/SH.H2O.SAFE.UR.ZS>. Accessed December 21, 2015.
- World Bank. (2015c). Improved sanitation facilities, urban (% of urban population with access). <http://data.worldbank.org/indicator/SH.STA.ACSN.UR>. Accessed December 21, 2015.
- World Bank. (2015d). *CO₂ emissions (metric tons per capita)*. <http://data.worldbank.org/indicator/EN.ATM.CO2E.PC>. Accessed January 4, 2016.
- World Economic Forum. (2014). *Global risks 2013* (9th ed.). Geneva: World Economic Forum.
- World Future Council. (2014). *Regenerative urban development: A roadmap to the city we need: 3rd Future of Cities Forum*. Hamburg: World Future Council.
- Zarfl, C., Fleet, D., Fries, E., Galgani, F., Gerdts, G., Hanke, G., & Matthies, M. (2011). Microplastics in oceans. *Marine Pollution Bulletin*, 62, 1589–1591.
- Zimmerman, K. A. (2012). Hurricane Katrina: facts, damage & aftermath. *Livescience*, August 27, 2015. <http://www.livescience.com/22522-hurricane-katrina-facts.html>. Accessed October 15, 2015.