REPORT | 2021

SMART WATER CITIES

PHASE 1: IDENTIFYING SMART WATER CITIES

K water

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It is my great pleasure to introduce the report "Identifying Smart Water Cities", the first output of the three-year project "Smart Water Cities" led by IWRA, K-water, and Asia Water Council (AWC). This report is the result of an intense collaborative work of which has brought together professionals and experts from different countries and disciplines – engineers, lawyers, natural scientists, and more – with a common interest to examine the challenges, the solutions, and the opportunities of using information and communication technology (ICT) in urban water management.

This project builds on a strong multi-year partnership between IWRA and K-water, initiated in 2017, when IWRA undertook analysis of Smart Water Management (SWM) initiatives from around the world. For this new project, IWRA welcomes the incorporation of the AWC, an organization with a good understanding of the possibilities and challenges of implementing smart water technologies in very different contexts in Asia, but also beyond the continent.

The Smart Water Cities project has a relevant and compelling mission: the development of a Global Standard and Certification Scheme for Smart Water Cities. This instrument will enable policy makers, developers, researchers, and innovators to analyze, compare, and benchmark diverse urban water systems and to identify strategies and courses of action for improving urban water performance. This present report takes the first step to identify existing practices and obstacles of using water ICTs in an urban environment and learning from them. It thus contributes to IWRA's mission to build strong water policies based on sound science.

The topic of the report is closely aligned with current trends and events. As we approach the two-year mark since the COVID-19 outbreak, ICT has shown poignantly how important it is for socioeconomic growth and development. By examining the contribution of ICT in urban water management, this report brings grounded knowledge on future opportunities for cities. Despite the difficulties and challenges that we currently face as a result of the COVID-19 pandemic, this report identifies and highlights exiciting and optimistic possibilities for the sector in the future.

Gabriel Eckstein
IWRA President 2019 -2021

December 2021

With the advent of a new era of transformation, focused on solving urban problems and fostering "4th industrial revolution" technology, the smart city model as emerged as a groundbreaking global concept. It is based on cutting-edge and innovative technology.

In particular, the emergence of a "Smart Water City" that integrates water management technologies such as flood prediction and drainage treatment, water and sewage facility management, and restoration of sound water circulation to respond to global climate change, is a key element of the smart city model. However, the definition of what makes for a successful Smart Water City is not yet clearly established.

K-water intends to devise an innovative, holistic, and customized smart water solution for any city, based on the competitiveness and competency required for sustainable integrated urban water management, while using new, renewable energy, and 4th industrial innovation technology from Korea.

Based on K-water's capabilities, we will lead the global understanding of what a Smart Water City is. To do this, we are conducting joint research on Smart Water Cities with the International Water Resources Association (IWRA), an international association of water experts. The goals of this joint research are divided into three parts:

- *First, to define the Smart Water City concept and current understandings of the entire water circulation process in a smart city.*
- *Second, to define a global performance standard for water management goals, including key performance indicators and customized solutions for each smart city sector.*
- *Third, to establish a plan for introducing an international smart city water management standard and certification system.*

This report is focused on the research outcomes of the first goal, deriving a universal definition of Smart Water Cities, and an understanding of the types of international standards that currently exist in relation to cities and urban water management. The research done here provides insightful guidance on the development of future smart city global water management indicators in the next phase.

Lastly, I would like to highlight the commitment of K-water in continuing to do our best to become the world's most comprehensive water platform company and leader in global water management for Smart Water Cities.

Park Jae-Hyeon,
K-water CEO

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LIST OF ACRONYMS

4IR	4th Industrial Revolution
AWC	Asia Water Council
BEDC	Busan Eco Delta City
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GNI	Gross National Income
ICT	Information and Communication Technologies
ISO	International Organization for Standardization
ITU	International Telecommunication Union
KPIs	Key Performance Indicators
OECD	Organisation for Economic Co-operation and Development
SDGs	Sustainable Development Goals
SWM	Smart Water Management
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNICEF	United Nations Children's Fund
WASH	Water, sanitation, and hygiene
WHO	World Health Organization
WMO	World Meteorological Organization
UN-Habitat	United Nations Human Settlement Programme
UN-Water	United Nations Water

INTRODUCTION

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The world population today is predominantly urban. The number of people living in cities has more than doubled over the last 45 years, going from 1.5 billion in 1975, to 4.3 billion in 2020. In relative terms, the proportion of people living in cities has also increased: while in 1975, 37% of the total world population lived in cities, this share grew to 56% in 2020 (OECD, 2020a). Cities are central elements in the development of human geographies. They are spaces where peoples, goods, and capital meet. City life is linked to many positive traits: cities symbolize modernization and cultural heterogeneity; they bring together diverse people with different sets of beliefs, customs, and traditions; and they spearhead countries' economic growth, technological innovation, and greater societal freedoms (Paunov, et al., 2019). Highly urbanised countries are generally associated with higher incomes, lower poverty rates, stronger and more resilient institutions, enhanced democratic accountability, and higher levels of gender equality.

These benefits aside, cities are currently facing large challenges. Urban life has been thoroughly impacted by climate change. The rise of the average temperature of the earth is one of the key drivers behind the increase of the frequency and intensity of extreme weather events, such as floods and droughts, which is directly affecting the life and wellbeing of millions of people and the environment (Rentschler & Salhab, 2020). Simultaneously, cities are key contributors to climate change. Although they occupy only about 3% of the world's land surface, estimates suggest that cities are responsible for 75% of global CO_2 emissions, with transport and buildings being among the largest contributors. They are also large energy consumers, representing almost two-thirds of total global energy consumption, and producing up to 50% of the world's solid waste (OECD, 2019). In addition, cities are growing at a great rate, taking up the land and the water of the surrounding urban areas, often prime agricultural land. Many cities around the world suffer from inadequate infrastructure and uneven access to basic services which have a particularly harmful impact on vulnerable groups (FAO, 2018). Indeed, city growth has made the provision of adequate housing and essential resources more challenging, and because of mass relocation of people from rural to urban areas, city slums have formed. In addition, social problems, such as unemployment and urban poverty have increased. Cities have thus become highly inequal: individuals who grew up in the poorest neighbourhoods earn 5-6% less than those who grew up in the most affluent, while life expectancy can vary by 20 years from one neighbourhood to another within cities such as Baltimore (USA) or London (UK) (OECD, 2019). These inequalities are posing questions as to how better prepare our societies for providing the necessary protections, healthcare, and welfare needed for a larger, aging, and more complex urban population.

The management of water resources and the provision of water services in urban areas have also posed serious challenges. The World Meteorological Organization (WMO) reports that water-related hazards have dominated disasters over the past 50 years, causing severe damage to cities (WMO, 2021). Disasters, such as storms and floods, have resulted in some of the largest human and economic loss. Between 1970 and 2019, storms and floods caused 635,932 deaths and brought about 636 billion USD in losses. Due to urbanization and increasing populations in cities, this water-related damage has a greater impact on city life. Urbanization impacts the water cycle. Urban surfaces are often covered by buildings, asphalt, and other materials. This prevents rainwater from being absorbed into the soil, thus interrupting the natural water cycle. Rainwater in cities can thus easily become contaminated when it encounters pollutants such as metals, litter, or oil. Polluted water then flows directly into the rivers.

Significant progress has been made in access to water services in the last 20 years, and thus over 1 billion people have gained access to piped water supplies between 2000 and 2015 alone. Improvements have been seen in Latin America and the Caribbean, Eastern Asia, and South-Eastern Asia. These regions are on track to achieve universal access by 2030. However, significant water, sanitation, and hygiene (WASH) challenges continue to exist. 844 million people still lack a service to secure basic drinking water, having to either use sources with water collection times exceeding 30 minutes, unprotected wells and springs, or to take water directly from surface water sources. These come with severe health risks. Basic sanitation is also largely inaccessible for a large proportion of the world population, particularly in the sub-Saharan Africa and Central and Southern Asia. While improvements have been reported, 2.3 billion people in the world still lack basic sanitation (UNICEF & WHO, 2019). Adequate surface water drainage continues to be problematic in both rural and urban areas.

Water service provisions tend to be better in cities than in rural areas across all world regions due to "economies of agglomeration", i.e., the fewer costs/per person of providing services in highly dense area (OECD, 2020a), but ensuring an adequate management of water resources and providing urban water services in larger cities are difficult tasks. Aging infrastructure is largely responsible for water leakage in cities. According to a study conducted by the World Bank, the world's annual volume of water loss is about 32 billion cubic meters. Developing countries, many of which are undergoing rapid urbanization, are responsible for approximately half this loss. Water leakage is detrimental to cities, as it leads to the waste and overconsumption of valuable resources. Water treatment facilities, which consume a lot of energy and water, must compensate for these losses. However, laying down new water mains, retrofitting water infrastructure, planning, and building adequate water treatment in urban areas are all technically complex and financially demanding measures. Besides, urban water measures are closely intertwined with other policies such as land use and spatial design, public services provision (electricity, gas, and transport), and social inclusion, etc. These measures involve actors with likely different and often conflicting interests. Under these circumstances, long-term planning and a comprehensive, inclusive, and robust approach to water governance framework is necessary.

Information and Communication Technologies (ICTs) have been called to play a key role as facilitators of change and progress for cities. Set against a background of large global trends, the use of ICTs is frequently presented as a powerful strategy for "smart" development, i.e., economic development that encompasses the use of ICTs and environmental sustainability. From this perspective, ICTs facilitate and make possible clean development in infrastructure and service provision in sectors as diverse as energy, buildings, transportation, waste, safety and security, health care, and education (ITU, 2016). The ultimate effects of these technologies cannot be predetermined, particularly in a changing international context of climate change, population growth, and pandemics. However, evidence of their positive impact has been documented (ITU, 2020).

The role of ICTs in urban water management, though relevant, poses challenges that require attention. Cities have thoroughly transformed natural water habitats: pavements and buildings have reduced water infiltration, increased water run-off, and pollution, as well as limited the recharge of groundwater supplies, amongst other steps. In addition, as centres for research and innovation, cities have been at the forefront of a fast-tracked trend to use intelligent technologies to provide solutions and improved services to existing and upcoming urban challenges. The number of local smart initiatives that carry the "Smart City" name has increased at great speed in the last two decades worldwide, showing a growing interest in how technologies can influence and change city life. These initiatives adjust to the local circumstances and have different features, but they all share the adoption of ICTs in local sectors and services as a desirable objective (OECD, 2020a).

In the urban water sector, the adoption of smart technologies has been growing steadily over the past decade – although at a slower pace than other sectors such as energy, transport, agriculture, and communication. Today we have examples of the use of smart water technologies in many different urban settings, and yet, despite the importance of water for the development of cities and of the increasing use of ICTs in the sector, we lack an adequate instrument to examine and compare urban water management in different cities, and the impact that ICTs may have in urban water systems.

The Smart Water Cities Project – Stage 1 Identifying Smart Water Cities
The present report is the first output of a three-year research project entitled "Smart Water Cities Project". The project, conducted collaboratively between K-water, AWC, and IWRA, aims to contribute to the knowledge sharing of smart water technologies in urban environments around the world and to promote their implementation (see Box 1).

The Smart Water Cities project's main objective is to develop an instrument for measuring and evaluating smart urban water management in cities around the world to form a global standard and certification scheme for Smart Water Cities. This instrument will serve to examine and compare the management of urban water resources both in existing cities (e.g., developing/developed cities; growing/shrinking cities) and in future cities being planned. This global standard and certification scheme will provide integrated and comprehensive information on the urban water status, and will offer advice and guidance to cities and communities for becoming smart(er) (e.g., what are the strengths of a city in water resources management? What should be improved in the city? How? In which area? With what kind of solutions/institutional frameworks/ resources would it help? etc.) The global standard and certification scheme will contribute to the development of capacities and decision-making functions of local water providers and communities as well as for authorities, in both a qualitative and quantitative manner.

Box 1. Smart Water Cities Project Organizations

K-water is a government-owned corporation for comprehensive water resource development, providing both public and industrial water in the Republic of Korea, established in 1987. K-water has a large pool of practical engineering expertise regarding water resources and has championed Smart Water technologies for several years.

The AWC is a non-profit, non-governmental organization established in 2015. The AWC is a new innovative regional cooperation body that sets solving the water issues faced by Asia as a core value, and aims to seek scientific and technological solutions and suggest concrete implementation plans.

The IWRA is a non-profit, non-governmental organization established in 1971. It is a cross-disciplinary, membership-focused, international association that uses events, projects, publications and research to facilitate and inspire dialogue, knowledge sharing, and science-based solutions for the sustainable management of water resources across all sectors, scales and communities at the interface between science and policy.

With this overall goal, the Smart Water Cities project is divided into three phases, each with their own objectives and tasks. The first phase, to which this report belongs, is called "Identifying Smart Water Cities". It contains two objectives:

- First, to examine the water urban challenges that cities face around the world, the global agenda on Smart Water Cities, the national/local policies and strategies on smart cities and water resources management, and the main features of a Smart Water City;

- Second, to analyze existing standards and certification schemes dedicated to urban sustainability and to learn from their examples.

This background work is fundamental. Identifying the water challenges that cities confront daily, as well as surveying the concepts, existing practices, and the debate on smart urban development, are necessary feats for developing an effective methodology for examining, comparing, and benchmarking Smart Water Cities around the world.

The other two stages of the project are entitled "Developing Standards" and "Certification". These phases will develop new standards framework and Key Performance Indicators (KPIs) for Smart Water Cities, respectively, as well as propose a new internationally recognised certification scheme for Smart Water Cities in the coming years (see Box 2).

Box 2. The Smart Water Cities Project

	PHASE 1 Identifying Smart Water Cities	PHASE 2 Developing standards	PHASE 3 Certification
Period	01.2021~12.2021	01.2022~12.2022	01.2023~12.2023
Goal	Analysis of Smart Water Cities, global agenda, regional/ national policies and strategies, global standards frameworks and certification schemes and case studies	Development of KPIs for Smart Water City and certification protocols	Pilot testing of the certification scheme and guidelines

Following the objectives of phase 1 of the project, the present report is divided into two main parts:

Part 1 defines what a Smart Water City is. To do this, it examines the main features of cities, the different functions that water fulfils in the urban environment and the water challenges that world cities are facing. From this examination, a Smart Water City is defined not just as a city that implements ICTs to provide water services, but one that improves urban sustainability and, ultimately, the quality of life of its citizen. This is in thanks to the adoption of these technologies in different stages of the urban water cycle, as well as to the adoption of sound policies and government strategies in close collaboration with relevant companies/agencies.

In addition, Part 1 provides illustrations of how cities around the world have dealt with current water challenges. Figure 1 presents 9 comparative case studies to show the variety of measures adopted in different contexts, their impact on people, communities, and the environment, and the barriers and enablers to their implementation. The cases have been written by scholars and practitioners that have submitted their case studies proposals in an open call issued by IWRA, K-Water and AWC. Their proposals were selected for development into case studies as part of this report. The full version by the authors can be found in the annex.

To ensure a diverse range of case studies for the report, various selection criteria have been employed. These include: the geographical location and type of city; respective water challenge; and national/local policies and strategies. As a result of this criteria, cases are diverse. Some concern small municipalities, such as Algarrobo in the south of Spain, whereas others, such as New York City (USA), represent larger and more complex cities. Some, such as Mumbai (India), are considered ancient cities, whereas others, such as the Busan Eco Delta City (BEDC), in Busan (Republic of Korea), have not yet been built. The challenges faced across these case studies are also diverse: water scarcity, flooding, water pollution, and infrastructure aging–to name a few. Some chapters, such as Heredia (Costa Rica) present a single urban challenge and a small-scale solution, whereas others, such as BEDC, take a larger viewpoint to consider various urban water challenges simultaneously and to present the urban solutions that authorities have adopted. Finally, the report presents examples of how a similar initiative has been implemented under different circumstances and with very distinct implications. Such is the case of Ciudad Juarez (Mexico), Hong Kong (China) and Mumbai (India) with the implementation of smart meters.

These cases do not seek to provide a prescriptive list of interventions that cities ought to put in place, or an exhaustive account of all smart solutions. Rather, they illustrate the status of urban smart practices in world cities today, as well as the successes, and occasionally also the failures, of urban smart water measures. All in all, these examples show how a multitude of institutions, technologies and practices have emerged and implemented with the aim to manage urban water resources more efficiently and to create more liveable cities. They present real-life evidence of the elements that a future global certification scheme for Smart Water Cities needs to be aware of and to take into consideration.

Figure 1. City Cases in the Smart Water Cities Project

Part 2 of the report examines and compares eight global standard indicators and certification schemes developed by different public and private organizations. The objective of this part of the report is to learn from these standards and to draw lessons applicable to the development of future certification schemes for Smart Water Cities.

Mumbay, India

These standards and certification schemes are well-known initiatives. They concern the local level, or city level, and deal with either of the three elements interlinked in the definition of Smart Water City: ICTs, water, and/or integrated management. They are the following:

- United 4 Smart Sustainable Cities
- ISO 37120 Series on Sustainable Cities and Communities
- OECD Smart City Measurement Framework
- CITYKeys Smart City Index
- LEED for Cities and Communities
- Arcadis Sustainable Cities Water Index
- KWR City Blueprint Approach
- AWS International Water Stewardship Standard

For each global standard scheme, Part 2 of this project examines the categories, the indicators, and the metrics that they employ. It also compares their general features, highlighting the strengths and weaknesses. When relevant, this section explains the procedures that potential certification applicants need to follow to receive both international certification and recognition from an international certification organization.

Gathering information about how other certifications and global standard frameworks operate is very helpful for identifying common practices and procedures. Standards and certification schemes have contributed to an understanding of what makes cities smarter, more liveable, and sustainable, and they have provided guidance on how to improve their performance. The analysis has also helped to detect the deficits in the existing approaches and to define the scope for a future Smart Water City certification scheme. Overall, the analysis provides a robust framework for later stages of the Smart Water Cities project and shows that developing indicators on urban water sustainability and smartness is a process: standards help to set more ambitious targets, constantly adopting new global agenda, policy, and strategies, as well as new technologies.

Finally, the conclusions summarize the main findings of the report and present the next steps of the project, outlining the roadmap for Stage 2 and Stage 3 of the project.

PART 1

SMART WATER CITIES

Cities around the world are hubs of innovation and creativity. They are at the centre of worldwide economic growth, trade and finance exchanges, communication, logistics, and are the homes for billions of people. With urban income levels about 21% higher than the national average, cities concentrate countries' wealth. They are also axes of cultural influence, driving transformation and reforms in all domains. With their great power of attraction, population of cities' is rising worldwide, expected to account for over 60% of the world's total population by 2030 (UNDESA Population Division, 2019; OECD, 2019).

Part 1 of this report examines the essential features of cities today and details the water challenges currently faced and likely to be confronted in the future. It also investigates the functions that water fulfils in the urban environment, and how ICTs can contribute to improving those functions. A definition of a Smart Water City is proposed following a discussion on the meaning of "smart development". This part of the report also presents different city cases from countries around the world to illustrate the urban water challenges and the technological and non-technological solutions that cities have put in place, including national and/or local policies and strategies. These case studies are further examined in the Annex of the report.

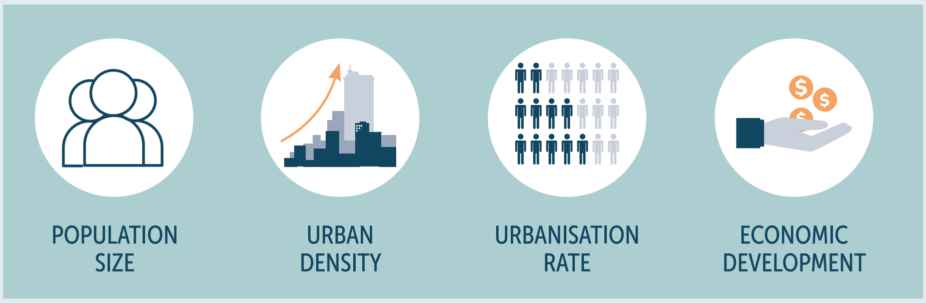
CHAPTER 1
CITIES: URBAN CHALLENGES AND GLOBAL AGENDAS

1.1. Cities and urban features

What is a city? More than 50% of the world population is considered to live in urban areas and yet, the characteristics of these areas vary enormously. Cities vary in terms of size and density, in socio-economic circumstances, in cultural factors, in governance, etc. Some have been built recently, others were inaugurated thousands of years ago. They vary in their natural features–climate, geography, orography, access to natural resources–as well as in their socio-economic factors and make up–industrialisation, urbanisation, and technological skill. Moreover, cities are constantly changing, adapting to shifting circumstances and developing their own features and characteristics. As such diverse circumstances concur, defining a city is not an easy task; however, the specialist literature identifies cities as made up of of three main elements: citizens, activities, and land/facilities (Lynch, 1960; Korea Planning Association, 2016). These elements, combined, derive into a definition of a city as a place where people gather and live, carry out their economic activities, and create and recreate their social and cultural values. Thus, the goal of an urban planning project should be to facilitate the ability for those people to undertake their individual and collective life projects in good health and freedom.

Understanding the different features of a city is important for adequate urban management. Ensuring that city inhabitants enjoy appropriate services such as water supply, water drainage, or sanitation, is significantly different in densely populated or in sprawling metropolitan areas, as well as in greener or in highly built-up areas. Some of the more relevant features of cities and urban trends are examined below. These include population size, urban density, rate of urbanization, economic development, and status as a new or old city.

Figure 2. Features of Cities



1. Population size

Cities vary in terms of their population (UN-Habitat, 2020b). For this, we distinguish between the following categories:

- **Megacities:** cities of over 10 million inhabitants
- **Large Cities:** from 5 to 10 million inhabitants
- **Medium-Sized Cities:** from 1 to 5 million inhabitants
- **Small Cities:** 500,000 to 1 million
- **Large Towns:** 300,000 to 500,000
- **Urban Settlements:** fewer than 300,000 inhabitants

Over the past fifty years, the number of people living in large urban clusters have increased and are expected to continue. In 1970, 63% of the total population lived in rural areas. 20% lived in urban settlements with fewer than 300,000 inhabitants, and the remaining 17% resided in large towns and cities. Nearly 50 years later, however, in 2018, thirty-three megacities in Africa, Asia, Europe, Latin America, and North America accounted for 7% of the world's total population; large cities concentrated another 4% of the global population; medium sized cities held 12% of the world population; small cities had around 5% of world population; large towns concentrated 4% of world population; and urban settlements with fewer than 300,000 inhabitants, brought around 23% of world population. Thus, while 36% of the world's population lived in cities in 1970, more than half of the population did so in 2018. The data shows that by 2018, the urban population had increased by almost three billion people, from 1.3 billion in 1970 to 4.3 billion in 2018. The overall population of megacities, although comparably small, soared almost tenfold, growing from 55 million in 1970, to 529 million inhabitants in 2018. This trend is likely to continue. Although the impact that the covid pandemic will have on population trends is unknown, according to estimates urban population will reach 5.5 billion people by 2035 – 62% of the total world population (UN, 2019). Every region is expected to become more urbanized. Over 95% urban growth is projected in the less developed regions of East Asia, South Asia, and Africa, while already highly urbanized regions are anticipated to grow at a slower rate (UN-Habitat, 2020a) (Table 1).

Table 1. Population Distribution of the World, by Rural/Urban Area of Residence and Size Class of Urban Settlement, 1970, 1990, 2018, and 2030.

Area of residence and size class of urban settlement (number of inhabitants)	Population Million - (%)				Example
	1970	1990	2018	2030	
Total	3701 (100)	5331 (100)	7633 (100)	8551 (100)	
Urban area	1354 (36.6)	2290 (43.0)	4220 (55.3)	5167 (60.4)	
Megacities (10 million or more)	55 (1.5)	153 (2.9)	529 (6.9)	752 (8.8)	Beijing (China); Istanbul (Turkey); Jakarta (Indonesia); **Mumbai (India)**; Tokyo (Japan)
Large Cities (5 million to 10 million)	107 (2.9)	156 (2.9)	325 (4.3)	448 (5.2)	**Hong Kong (China)**; London (UK); **Ningbo (China)**; **NYC (USA)**; Seoul (ROK)
Medium-Sized Cities (1 million to 5 million)	244 (6.6)	467 (8.8)	926 (12.1)	1183 (13.8)	Berlin (Germany); **Ciudad Juarez (Mexico)**; Kuala Lumpur (Malaysia); Paris (France); Rome (Italy)
Small Cities (500,000 to 1 million)	131 (3.5)	208 (3.9)	415 (5.4)	494 (5.8)	Amsterdam (Netherlands); Colombo (Sri Lanka); **Nakuru (Kenya)**; Stockholm (Sweden); Vancouver (Canada)
Large Towns (300,000 to 500,000)	87 (2.3)	159 (3.0)	275 (3.6)	320 (3.7)	Addis Ababa (Ethiopia); Bonn (Germany); Canberra (Australia); Cape Town (South Africa); Sochi (Russia); Zurich (Switzerland)
Urban Settlements (Fewer than 300,000)	730 (19.7)	1147 (21.5)	1750 (22.9)	1971 (23.1)	**Algarrobo (Spain)**; **Busan Eco Delta City (ROK)**; **Heredia (Costa Rica)**; Siem Reap (Cambodia); Thimphu (Bhutan)
Rural area	2346 (63.4)	3041 (57.0)	3413 (44.7)	3384 (39.6)	

* Case Study Countries are shown in bold / Source: UNDESA Population Division, 2019

Figure 3. Urbanization Trend

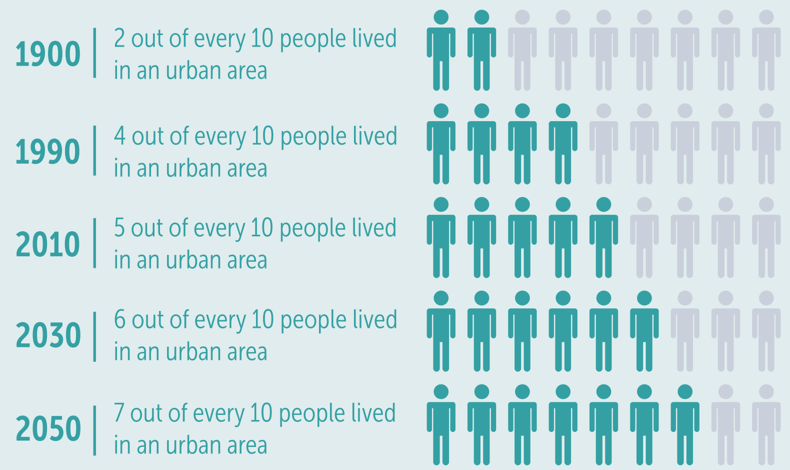
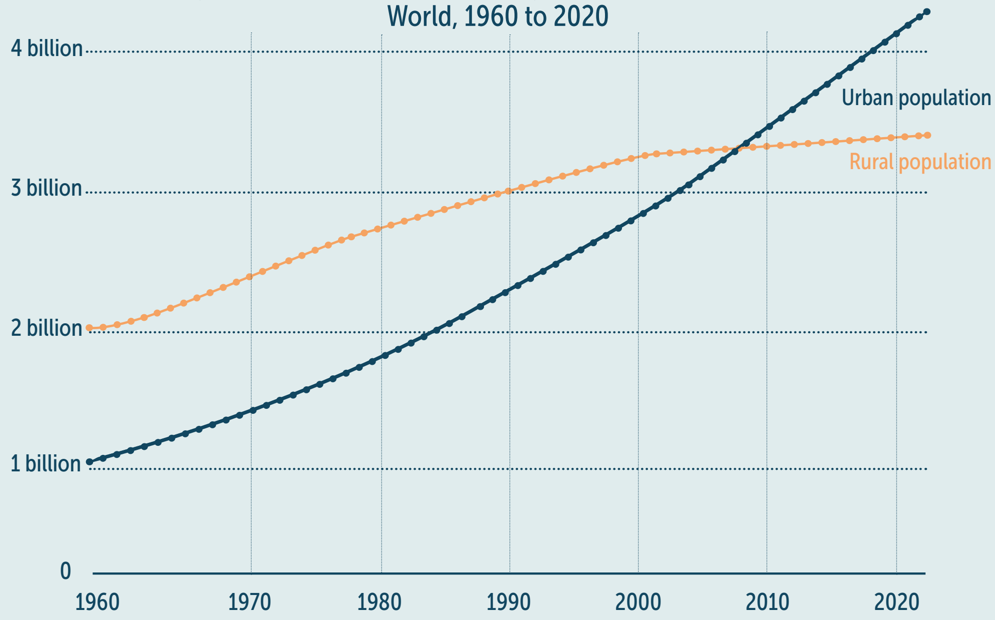


Figure 4. Number of People Living in Urban and Rural Areas, World, 1960 to 2020



Source: World Bank based on data from the UN Population Division.
Note: Urban populations are defined based on the definition of urban areas by national statistical offices.
Our World in Data.

2. Urban density

Urban density refers to the number of people living in a city per unit area. Four degrees of urban density are identified (UN-Habitat, 2020b):

- **Very High-Density Cities:** more than 8 000 inhabitants/km^2
- **High Density Cities:** between 6 000 and 8 000 inhabitants/km^2
- **Dense Cities:** Between 4 000 and 6 000 inhabitants/km^2
- **Lower-Density Cities:** fewer than 4 000 inhabitants/km^2

Table 2. Examples of Urban Density of World Cities

Urban Density	Examples
Very High-Density Cities (More than 8000 inhabitants/km^2)	Colombo (Sri Lanka); **Heredia (Costa Rica)**; Jakarta (Indonesia); **Mumbai (India)**; **New York City (USA)**; Paris (France); Seoul (ROK)
High Density Cities (Between 6000 and 8000 inhabitants/km^2)	**Busan Eco Delta City (ROK)**; **Hong Kong (China)**; Kuala Lumpur (Malaysia); Tokyo (Japan)
Dense Cities (Between 4000 and 6000 inhabitants/km^2)	Berlin (Germany); **Ciudad Juarez (Mexico)**; London (UK); Stockholm (Sweden); Thimphu (Bhutan); Vancouver (Canada); Zurich (Switzerland)
Lower-Density Cities (Fewer than 4000 inhabitants/km^2)	**Algarrobo (Spain)**; Amsterdam (Netherlands); Beijing (China); Bonn (Germany); Canberra (Australia); Cape Town (South Africa); Istanbul (Turkey); **Nakuru (Kenya)**; **Ningbo (China)**; Rome (Italy); Sochi (Russia)

* Case Study Countries are shown in bold

Information about urban density around the world shows that cities everywhere are dense, but not equally so. In general, larger cities tend to be denser. In addition, a correlation is established between the income of a country and the density of its cities: cities in low-income countries are almost four times denser than cities in high-income countries. Globally, cities have continuously become denser over the past 40 years. The increasing density of large and very large cities (of more than 1 million inhabitants) is the main driver of the global increase in population density (OECD & European Commission, 2020).

Urban density has implications on urban services: low-density cities need to spend more on infrastructure to offer the same level of service, as there is more space to cover. The existing evidence suggests that a shift from moderate to low density leads to a bigger increase in costs, while a shift from high to moderate levels of density has less of an impact (OECD and European Commission, 2020).

3. Rate of urbanization

As well as measuring the population size and density, cities also vary according to the average rate of change of the urban population over a period of time (i.e., how fast a city grows). The rate of urbanization between 1950 and 2018 around the world was 0.92% per year on average. However, urbanization has occurred at faster rates in less developed regions, which have reached a higher number of larger cities in substantially less time than developed countries (UN, 2019). Conversely, in many developed countries, cities are shrinking. Examples of this exist in USA, Japan, and Europe. Declining population is often linked to processes of de-industrialisation and migration (UN-Habitat, 2020b).

Knowing the rate of urbanization for a city can illuminate potential challenges that the city might have in providing adequate water services to the population. A city growing at a greater rate, for example, may have difficulties in ensuring the supply of WASH services to its population. Conversely, cities with declining populations face a different type of challenge, caused by the difficulties of maintaining an infrastructure and a level of service originally planned for a larger population. ICTs may provide adequate solutions to shrinking cities via remote services.

Table 3. Rate of Urbanization in the World, by Development Group, Selected Years, and Periods, 1950-2050

Development Group	Rate of Urbanization (%)				
	1950-1970	1970-1990	1990-2018	2018-2030	2030-2050
World	1.06	0.80	0.90	0.74	0.62
More Developed Regions	0.99	0.40	0.30	0.28	0.31
Less Developed Regions	1.78	1.61	1.33	0.94	0.73

Source: UNDESA Population Division, 2019

4. New or existing city

Cities' population can grow either through densification within old city borders, or through the creation or expansion of cities on unbuilt land. Studies on the topic show that on average, 65-70% of population growth of cities since 1975 has occurred through densification. This pattern has become stronger over time. In the period from 1975 to 1990, 65% of city population growth had happened within cities' old boundaries. Between 2000 to 2015, however, the percentage increased to 71%, while 29% reflected the urbanization of new areas (OECD, 2020a).

The challenges that these two different strategies create on urban infrastructure and city planning are very different and need to be considered. Urban densification imposes pressures on old infrastructure, which will likely need repairing and retrofitting to meet new demands. For its part, new urban development allows the installation of new smart infrastructure from scratch, but also requires an appropriate estimation of future uses and needs. These two different endeavors entail different costs, knowledge, and resources.

On this topic, the UN advises that when new developments are needed to accommodate population growth, they should be established at the periphery of existing cities and with the purpose of promoting compact and contiguous urban developments (UN, 2019). The objective is to avoid creating whole new cities from zero, which tends to be very expensive. It is also argued that new developments should be on lands of lower environmental and agricultural value, to minimize the environmental impact that urbanisation and city expansion may have on nature. The UN also argues for a proper design of new urban developments to make them both liveable and sustainable (UN, 2019).

5. Economic development

Cities also vary according to their economic development. The World Bank has adopted a classification that assigns the world's economies to four income groups: low, lower-middle, upper-middle, and high-income countries. The classifications are updated each year based on Gross National Income (GNI) per capita. The values in 2020 were the following:

- Cities in high income countries have a GNI per capita superior to 12,535 USD.
- Cities in upper-middle income countries have a GNI per capita between 4,046 and 12,535 USD.
- Cities in lower-middle income countries have a GNI per capita between 1,036 and 4,045 USD.
- Cities in low-income countries have a GNI per capita below 1,036 USD.

Table 4. Examples of Economic Development of World Cities

Economic Development	Example
High Income Countries (More than 12,535 USD GNI Per Capita)	Australia; Canada; France; Germany; **Hong Kong (China)**; Italy; Japan; Netherlands; **ROK; Spain**; Sweden; Switzerland; UK; **USA**
Upper-Middle Income Countries (Between 4,046 and 12,535 USD GNI Per Capita)	**China; Costa Rica**; Malaysia; **Mexico**; Russia; South Africa; Turkey
Lower-Middle Income Countries (Between 1,036 and 4,045 USD GNI Per Capita)	Bhutan; India; Indonesia; **Kenya**; Sri Lanka
Low Income Countries (Less than 1,036 USD GNI Per Capita)	Afghanistan; Ethiopia; Liberia; Somalia; Yemen

*Case Study Countries are shown in bold

Both the socio-economic and technological performance of a country are defined by its degree of economic development. Economic development is a critical component with a large impact on industrial attainment and innovation, educational and cultural performance, financial development, and an improved quality of life. For this, we expect high income cities to have more access to the technologies as well as the financial resources required to develop SWM in urban developments. We expect lower income cities will be more likely to face difficulties. Proposals to introduce solutions in cities with different degrees of economic resources need to be responsive to these circumstances to ensure overall effectiveness and sustainability. Thus, while introducing smart solutions in high-income cities might involve further expanding its ICT infrastructure, low-income cities might give priority to smart solutions for flood prevention and stable water supply. Smart urban water planning is aware of these financial constraints.

1.2. Key challenges in world cities today

Regardless of their different and specific urban features, world cities today are facing common challenges. As people flow into cities, access to fundamental resources such as land, water, and energy is coming under heavy stress. City growth has put pressure on the land and on the provision of adequate housing, food, and transportation, with slums resulting from the huge relocation of people from rural to urban areas. Social problems such as unemployment, social exclusion, poverty, and inequality have increased in many cities worldwide. Improving governance and management in these urban enlarged and complex cities is frequently referred to as a main societal challenge for countries today (OECD, 2019).

Climate change is also impacting urban life. Over the last 50 years, the death of millions of people has resulted from climate change-related hazards and disasters. Weather, climate, and water hazards are considered responsible for 50% of all disasters, 45% of deaths, and 74% of global economic losses–which are largely affecting cities (WMO, 2021). Simultaneously, cities contribute to climate change, pollution, and environmental degradation. Cities growth is behind poor air and water quality, waste-disposal problems, and the destruction of natural ecosystems. Cities are large energy consumers, requiring an uninterrupted supply of energy estimated to account for 75% of global energy use today. Comprehensive urban planning practices that incorporate city green spaces, reduce energy consumption, and favor circular economy strategies are thus considered to be central for the development of cities in the future.

These urban challenges are enduring. International organisations emphasise that the speed of population growth will bring a variety of challenges: 3 billion people–around 40% of the world's population–will need access to adequate housing by 2030 (UN-Habitat, 2020b), while food and non-food agricultural production is expected to rise (FAO, 2018).

With regards to water, the expansion of cities is creating well-documented challenges both in the management of urban water resources and in the provision of urban water and sanitation services. Indeed, city growth, climate change, and urbanization have all impacted the natural water cycle, and cities, today, are at the centre of environmental disasters such as floods and tropical storms which pose great threats to the life and wellbeing of thousands of people and to the environment. The expansion of urban areas is creating difficulties in the provision of adequate drinking water and sanitation in many areas of the world, as well as making it difficult to manage the expansion and renewal of water networks in enlarged urban areas.

The character and implications of five major water challenges are considered in more detail below.

1. Flooding
Floods have caused some of the largest human and economic losses in the last 50 years (WMO, 2021). Floods might be caused due to proximity to coastal areas or rivers and/or the geology or topography of a particular city. In cases when an urban area has inadequate drainage (or no draining at all), urban flooding also occurs. Floods have enormous impacts on both individuals and communities, and have large social, economic, and environmental consequences. Damages from floods are not only direct and immediate, but they can also expand to supply chains and transport networks, affecting a city's future developments as well. Currently, nearly 20% of the world population are directly exposed to floods, and this annual flood damage to urban property alone amounts to over USD 120 billion annually, half of which is in North America (Sadoff, et al., 2015).

Indeed, many cities around the world have faced flooding in the past and are regularly on alert for flooding risks. Some of the cities facing episodes of severe flooding are Nagoya and Osaka (Japan), Miami, New York City, and New Orleans (USA), Gugzhou and Shenzhen (China), Paris (France), Ho Chi Minh City (Vietnam), Jakarta (Indonesia), and Manila (Philippines).

In this report, we see the case of Ningbo, a large coastal city in Eastern China that has experienced numerous events of flooding in the last 50 years. Ningbo has been ranked one of the top 20 global port cities most prone to flooding risk during the typhoon season, when tidal surges and intense rainfall are frequent. The risk of coastal flooding in Ningbo is expected to rise by 2050 because of population growth, urbanization expansion, and land subsidence. In the last decades, New York City (USA) has also been experiencing an increase in sewer overflows and floods caused by heavy rainfalls. This trend is expected to persist in the future, causing difficulties not only for the provision of water services to residents, but also damaging the coastal water bodies of the city.

2. Water scarcity
Water scarcity refers to the lack of access to adequate quantities of water for human and environmental uses (UNICEF, 2021). It is caused by natural phenomena, human influences, or a combination of both (i.e., physical water scarcity, drought), as well as because of a lack of suitable infrastructure to ensure access to the existing water resources (i.e., economic water scarcity).
Water scarcity causes severe restrictions and temporary interruptions to the water supply. This leads to higher operation and maintenance costs for industrial users and energy producers, income losses and competitive disadvantages in the agricultural sector, and losses in activities dependent on public water, like tourism (Spinoni, et al., 2016). It is estimated that droughts can limit a city's economic growth by 12% (Zaveri, et al., 2021). Water scarcity is currently affecting urban population: out of over 4 billion people living in urban areas, 143 million lack access to drinking water and 605 million are without access to at least basic sanitation facilities (WHO & UNICEF, 2019). It is expected that, by 2050, 685 million people, living in over 570 cities, will face an additional decline in freshwater availability of at least 10%. Water deficits are linked to 10% of the rise in global migration.

Evidence exists of water stress in cities such as Cape Town (South Africa), London (UK), Venice (Italy), São Paulo (Brazil), Bangalore (India), Cairo (Egypt), amongst many others. In some cities, such as Amman (Jordan), Cape Town (South Africa) and Melbourne (Australia), this decline in freshwater availability might be between 30 to 49%, while Santiago (Chile) may see a decline that exceeds 50% (UNESCO & UN-Water, 2020). This report provides two different examples of water scarcity. First, the Algarrobo (Spain) shows how the volume of water available in the local reservoir has halved in only a decade, going from 102 hm^3 in 2011, to 50 hm^3 in 2021. This change has put the agriculture and tourism-dependent local economy at risk. Second, Nakuru (Kenya), Africa's fastest-growing city and the fourth in the world, currently faces a daily demand of water of 70,000 m^3, while the available volume is 45,000 m^3. The demand for water is expected to rise significantly to reach 191,000 m^3/d in 2050 to serve the estimated population. These cases describe the difficulties that water scarcity is creating and the measures that have been proposed and implemented to try to deal with this challenge.

3. Deficient water quality

Water pollution, either point source or diffused, is causing inadequate water quality in many catchment areas around the world. Pesticides, fertilizers, salinization, chemicals, heavy metals, oils, etc., are some of the harmful substances reaching our water bodies. In cities, the lack of urban wastewater collection and treatment as well as the street runoff contaminants are pervasive problems. Pollution, at best, generates additional costs in ensuring access to safe water for the population. At worst, this circumstance means that water, not fit for purpose, is being distributed to water users and customers, transmitting diseases such as diarrhoea, cholera, dysentery, typhoid, and polio. Contaminated drinking water is estimated to cause 485,000 diarrhoeal deaths each year (WHO, 2019).

Many cities around the world including Pittsburgh (USA), Beijing (China), Mexico City (Mexico), Lagos (Nigeria), Caracas (Venezuela) have reported inadequate quality in their drinking water (World Resources Institute, 2018). In this report, we follow the measures that the city of Heredia, in Costa Rica, has put in place to deal with the deficient drinking water quality in the city. Heredia's water supply comes partly from surface waters with heavy sediment load, which makes human consumption difficult.

4. Aging or insufficient infrastructure

Problems such as infrastructure breakdown, failing pumps and motors, and water leaks are regularly reported across the world. Obsolete infrastructure is considered the cause of an average of 21% of water loss before distribution, threatening universal coverage of drinking water and sanitation and diminishing the capacity to protect citizens against water-related disasters. Significant investment is required to renovate and improve water infrastructure. This may include water supply networks, which on many occasions, are several decades old. According to OECD (2016), a total of 92% of surveyed cities (48 cities from OECD and non-OECD countries) have reported significant challenges in terms of updating and renewing these water infrastructures. Along with aging infrastructure, cities also suffer from inadequate water supply and sanitation infrastructure, unable to keep up with the population and urbanization growth. Globally, by 2050, the required investment for water supply and sanitation is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estimated at 6.7 trillion dollars. This bill can triple by 2030, considering the wider range of water-related infrastructure required (OECD, 2020b).

In this report, two examples of the challenges of an aging and insufficient infrastructure are presented. In Ciudad Juarez (Mexico), the authorities calculated that water leakage affected 47% of the total volume of water distributed. Mumbai (India), a megacity of over 8.5 million inhabitants, has approximately only 300,000 water meters. Such situations make it very difficult to provide accurate estimations of the populations' actual water needs, and to protect and manage the already strained local water resources. Details of the measures that the cities put in place are examined in further detail in the Annex.

5. Inadequate urban water planning

Beyond providing drinking water, sanitation services, dealing with aging infrastructures, cities also face problems due to poor planning practices. This challenge recognises that smart urban water management also fulfils other functions relating to environmental protection, health and well-being, social connection, emotional balance, and happiness. Adequate water infrastructure planning concerns more than just guaranteeing safe water services provision; it also regards the promotion and the conservation of water resources and the protection of urban ecosystems. Access to safe, open, and green water areas in cities (including coastal or waterfront spaces, fountains, parks, and green areas) promotes wellbeing and inclusion, as well as helps citizens to develop positive social interactions and healthy activities. These measures can also contribute to mitigating the impacts of floods and rising sea levels.

Busan, the second largest city in the Republic of Korea, aspires to adopt a friendlier urban design when it comes to access to water leisure and recreational area. The BEDC is a new development project planned to be built to the west of the city of Busan by 2028. One of the most distinctive challenges taken up by the authorities has been to facilitate public access to green and blue areas (parks, riverside, and wetlands) in the city, and to integrate nature into the other functions of the city – provision of commercial and business spaces, residential areas, and leisure and cultural zones. But improvements in the urban design of the cities can also be undertaken in existing cities via smart water solutions. Hong Kong (China) presents a very peculiar situation. Although it is an inherently water scarce city, water supply has been ensured thanks to an inter-basin transfer scheme bringing water into the city, which has resulted in an over-allocation of water for the city. A current smart metering pilot project is aiming to limit overuse of water and to promote its conservation.

Table 5 presents a comparison of the country cases reflected in the Annex that this report explores in detail. It is important to keep in mind that many of the city cases presented here face not only one, but several of the water challenges described. Water scarcity, insufficient infrastructure, and deficient water quality, for instance, are often simultaneously present. Table 5 highlights the challenge that the city has addressed more explicitly and directly, but any intervention on one of the challenges has an impact in the overall water status of a city.

Table 5. City Cases in the Report

City	Country	Region	Type of City			Type of Challenge Addressed
			Population	New or Existing Urban Development	Economic Development	
Algarrobo	Spain	Europe	Urban Settlements	Existing	High-Income Economy	Water Scarcity
Busan Eco Delta City	Republic of Korea	Asia & The Pacific	Medium Size	New	High-Income Economy	Inadequate Urban Water Planning
Ciudad Juarez	Mexico	North America	Medium Size	Existing	Upper Middle Income	Aging or Insufficient Infrastruc-ture
Heredia	Costa Rica	Latin America & The Caribbean	Urban Settlement	Existing	Upper Middle Income	Deficient Water Quality
Hong Kong	China	Asia & The Pacific	Large City	Existing	High-Income Economy	Inadequate Urban Water Planning
Mumbai	India	Asia & The Pacific	Megacity	Existing	Lower Middle Income	Aging or Insufficient Infrastruc-ture
Nakuru	Kenya	Africa	Small City	Existing	Lower Middle Income	Water Scarcity
New York City	USA	North America	Large City	Existing	High-Income Economy	Flood Risks
Ningbo	China	Asia & The Pacific	Large City	Existing	Upper Middle Income	Flood Risks

1.3. The global agenda for smart and sustainable development of cities

In the last 20 years, the international community has given particular attention to global urban water challenges. Several international agreements and guidelines have been adopted with the aim to coordinate an international response to these events. These agreements constitute a global agenda with a shared vision, goals and targets, and a plan for common action. Many of these international initiatives identify cities as central actors. Engaging with the city level has thus been considered crucial, and city authorities can follow international strategies while adjusting them to their local particularities. For this reason, many international agreements frequently establish objectives that require substantive progress at the city level.

The most comprehensive initiative touching upon urban water management has been the adoption of 2030 Agenda for Sustainable Development by the United Nations in 2015. The 2030 Agenda spells out the Sustainable Development Goals (SDGs), which is a collection of 17 interlinked global goals designed to be a "blueprint to achieve a better and more sustainable future for all" (UN, 2017). Agreed upon by governments around the world, the SDGs specify 169 targets in a wide range of areas, including poverty alleviation, economic growth, and environmental objectives. Two SDGs are particularly dedicated to water and to cities. They are Goal 6 and Goal 11:

- **Goal 6** aims to ensure availability and sustainable management of water and sanitation for all by the year 2030.
- **Goal 11** focuses on making cities inclusive, safe, resilient, and sustainable, by aiming to reduce the impact of disasters, reducing the environmental impact of cities, and by increasing the universal access to green and public spaces.

Figure 5. Sustainable Development Goals

To facilitate the implementation of the SDGs, other measures leading to their achievement have been adopted. With regards to goal 6, the UN declared 2018-2028 as the International Decade for Action "Water for Sustainable Development", a period when the UN family of organisations will carry out a series of actions to improve water sustainability and availability. Also, with the adoption of the UN 2030 strategy and the SDG 6 global acceleration framework, the UN has shown commitment for water action at the international level. Their

focus has been on accelerating progress towards the targets of SDG 6. These measures aim to provide support to monitoring and reporting at the global, regional, and sub-regional levels, to facilitate outreach and communication activities through publications and global campaigns, to provide technical advice, and to assist countries to identify top priorities.
SDG 11 has also received further attention. UN-Habitat has played a role in assisting national and local governments with the implementation of the city-related targets. With the adoption of the "Goal 11 - monitoring framework" and the UN-Habitat new urban agenda, endorsed by the UN General Assembly in 2016, the UN has argued that adequate urbanisation can help with attaining sustainable development targets. UN agencies have provided aid for the collection and analysis of urban data and assistance for the preparation of country-based reports.

Other key agreements concerning sustainable development have also given a central role to local urban action. The Paris Agreement, for one, is the landmark global agreement to combat climate change, and the Sendai Framework provides concrete actions for protecting development gains from the risk of disaster. Both these agreements indicate how crucial it is to engage citizens and urban authorities in taking action that limits runaway global warming and the impact of weather-related hazards at the local level. In fact, it is estimated that up to 65% of SDGs targets might be at risk if local urban stakeholders are not assigned a clear role in the implementation of the agenda (Kanuri et al., 2016).

Figure 6. Benefits of Smart Cities

Source: Woetzel et al. (2018)

To deal with these urban problems, the promotion of "smart" urban development has been considered a desirable objective, with smart technologies as central instruments for addressing and achieving solutions to urban challenges. The purpose of smart cities has been to improve policy efficiency, reduce waste and inconvenience, improve social and economic quality, and maximize social inclusion. The use of data and technology has been an influential global trend aiming to better decision-making at the city level. Data on the ICT access and

Hong Kong (China)

usage (including access to computers, fixed and mobile internet broadband, use of the internet for professional, services and leisure, etc.), have shown a constant progression in all fields and socio-economic sectors across the world since the 1990s. The COVID-19 pandemic has recently accelerated these progressions. Taking steps to introduce ICTs has been one of the main strategies for meeting global challenges. We have witnessed initiatives for introducing smart technologies in sectoral policies such as transport, energy, education, natural resources management, and in the provision of many different services.

At the global level, international organizations have supported this trend to put smart cities at the forefront of a common global action. The “People-Centered Smart Cities Programme” is one of UN-Habitat’s five global flagship strategic action programs. The program has emphasized how digital technologies can help to reach SDGs by improving livelihoods, economic, and gender equity, while at the same time recognizing the many challenges that ICTs themselves pose. For this reason, UN-Habitat has made efforts to enable the establishment of long-term partnerships with national and local governments and other stakeholders to facilitate an appropriate transition towards a wider use of smart technologies.

The United Nation has also spearheaded an initiative entitled, United 4 Smart Sustainable Cities (U4SSC) with the participation of the International Telecommunication Union (ITU), the United Nations Economic Commission For Europe (UNECE) and UN-Habitat, launched in May 2016. This initiative aims to provide cities with the criteria and the means to evaluate their contributions in making cities smarter and more sustainable.

Overall, these initiatives show that smart urban development has been at the top of the global agenda for international organizations. However, while international agreements provide guidance, the responsibility for defining and executing these measures, policies, and treaty goals lie within each UN member state. The next chapter examines some of smart water initiatives that have been implemented in different countries in the Americas, Europe, Africa, and Asia. These case studies help to identify the main features of a Smart Water City and show how ambitious actions in cities are critical to meeting global targets.

CHAPTER 2
SMART WATER CITIES

2.1. Functions of water in cities

Meeting the basic need for safe drinking water and sanitation has been the key objective in water resources management at the city scale. Drinking water and sanitation have been services traditionally provided by local water services suppliers, either public or private. Ensuring that these essential demands for water services are met has been a condition for societal well-being and socio-economic development. Therefore, water planning authorities have put the provision of urban water services at the centre of development plans.

In addition to meeting these basic needs, water serves other equally important functions, as well, and these can best be understood by examining the concept of "water cycle". The water cycle refers to the constant movement of water in Earth's atmosphere. This process takes place through five different stages (condensation, precipitation, infiltration, runoff, and evapotranspiration) over four spheres (atmosphere, lithosphere, hydrosphere, and biosphere) and in three different forms (liquid, solid (ice), and vapor). The water cycle is frequently illustrated with a model representing the circulation of water in the watershed – see Figure 7.

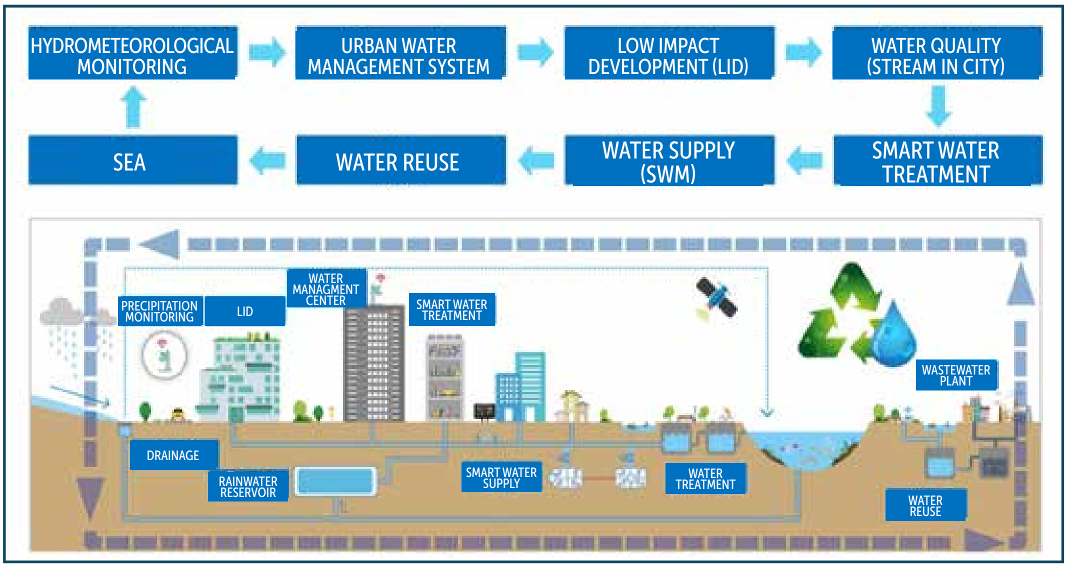
Figure 7. The Water Cycle

At each stage of the water cycle, water fulfils important functions: it regulates the temperature of its surroundings; it erodes rocks and converts them into soil; it produces minerals that then circulate in the different spheres; and it transforms and creates geographical features, etc. In short, water does not only serve human needs, but it also modifies the environment and creates the conditions for human, animal, and plant life, as well as for ecosystems to survive. Significantly, the water cycle also represents the idea that any prospective intervention at any stage of the water cycle can have an impact in all subsequent stages.

Human activity has changed and disrupted the water cycle: irrigation, abstractions, storage, deforestation, desalination, etc. are all common human activities with implications in how water continues to circulate through the different phases of the water cycle. Cities above all have altered the water cycle in such a way that experts propose to use the term “urban water cycle” as a distinct and differentiated concept to the natural water cycle (Marsalek, et al., 2008).

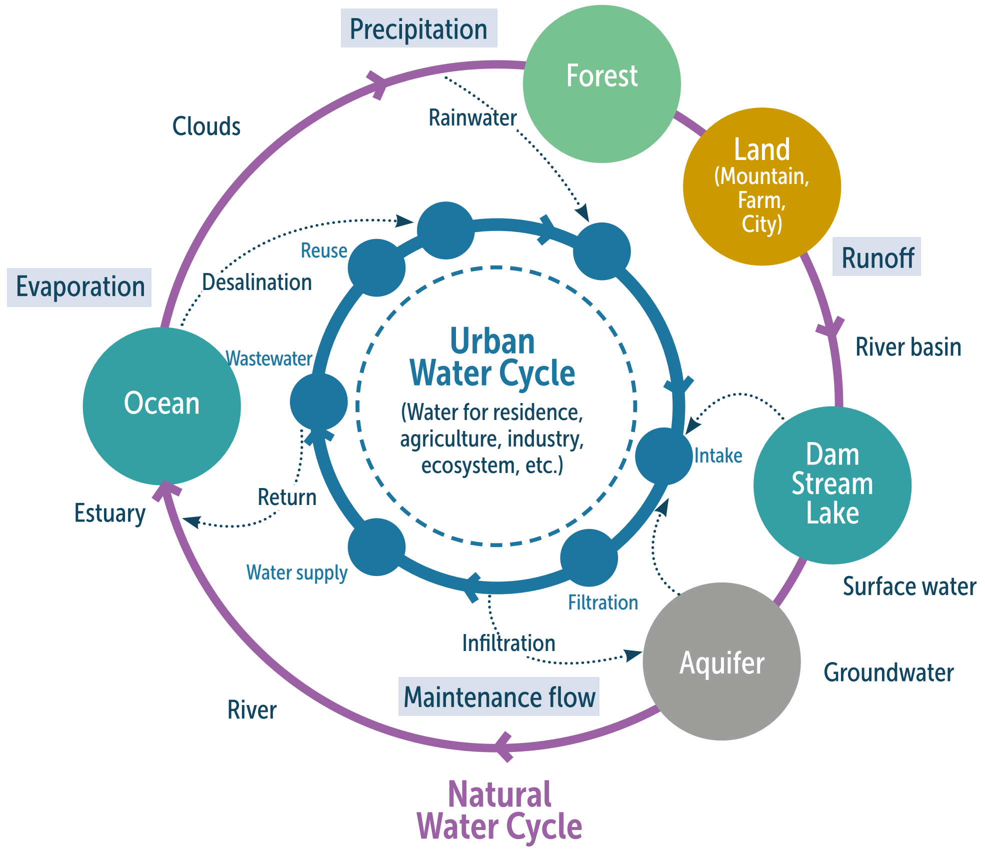
In urban settings, the principal structure of the water cycle remains the same, but certain key aspects have changed because of phenomena such as urbanization, industrialization, and population growth. Human activities destined to treat water resources and bring them to human-acceptable standards have changed water’s journey from catchments through reservoirs and treatment to domestic taps, and from households to nature. Concrete and pavements found in cities limit water infiltration and create run-offs, which have brought pollution and waste into storm water systems as well as have limited the replenishment of groundwater aquifers. These have consequences on the water available for abstraction. In short, human intervention has modified water circulation at the city level, altering the quality and the availability of water resources– See Figure 8.

Figure 8. The Urban Water Cycle



An understanding of the different functions of water needs to be at the core of any smart and integrated urban planning project. Indeed, awareness of what water does at different stages of its water cycle, and what effects cities have on water resources and the environment, can help to plan cities in a more integrated, effective, and sustainable manner. Smart water technologies have a role to play in providing improved water services to city inhabitants, but they are also called on to improve urban planning practices by enhancing urban ecosystem's resilience and aiding in human coexistence with nature. Smart water technologies are tools that can help manage water resources more efficiently and sustainably, facilitating that water also fulfils other key functions beyond the (critical and indispensable) supply of safe drinking water and sanitation in a city. Such understanding is essential for the development of Smart Water Cities.

Figure 9. The Natural and Urban Water Cycles



2.2. What is a Smart Water City?

To examine the concept of "Smart Water City," it is necessary first to examine what a "smart city" means. The concept of "smart city" has become a promising aspiration to deal with the challenges that world cities face nowadays. The term refers to improving the quality of life via the use of ICTs in different sectors of the urban environment (including water, transport, energy, education, etc.). The origin of the concept goes back to the 1980s, to the initial development of computers and robotics, the expansion of the internet, the formation of large technological companies,s and new industrial clusters such as Silicon Valley. The 'smart city' concept appeals to views about highly engineered and competitive cities (Glasmeier & Christopherson, 2015).

Different definitions and criteria for identifying the main features of a smart city exist (For a discussion on the "smart city" concept, see Ahvenniemi, et al., 2017; Albino, et al., 2015). The United Nation has defined a smart city as "an innovative city that uses ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness–while also ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects" (UNECE, 2015). For this approach, the use of ICTs is inextricably linked to the impact of such technology. A smart city is not only a city that implements ICTs, but is one that reports substantial and measurable improvements in the urban sustainability and the quality of life of local actors because of the implementation of these technologies. Thus, smart interventions pay careful attention to the target population whose needs are being addressed, the circumstances of where the intervention is proposed, as well as impact to future generations and the environment. This understanding goes beyond characterizing a smart city as a city that exclusively employs technologies in the provision of services to its citizens (be it transport, communications, infrastructure, logistic, or energy systems, or all of them combined). It also concerns the impact of the use of ICTs in everyday urban life. A smart city pays attention to, for instance, the number and uptake of technologies by citizens and organizations or the length and strength of the ICTs network, as well as the social and the environmental consequences of their use.

For the definition of "Smart Water Cities" the present report builds, along with the UN's definition of a smart city, on the "Smart Water Management - Case Study Report" edited by IWRA and K-water. This report examined the use of integrated, real-time information and ICTs solutions, such as sensors, monitors, Geographic Information System (GIS), satellite mapping, and other contactless, intelligent tools in both urban and agriculture water management. The report presents evidence of how SWM has provided solutions at different scales and across various urban and rural contexts, and how they have impacted the social, economic, environmental, governance, and technological spheres. It provided evidence of how SWM projects can aid in the achievement of the SDGs by improving livelihoods and economic and gender equities, reducing hunger, broadening access to knowledge and education, enhancing health and wellbeing, adapting to climate change, and improving safety. In addition, the report also argued for establishing an adequate governance and regulatory framework to support the implementation of smart and sustainable water projects and initiatives.

With this understanding, a Smart Water City is defined to include the use of ICTs in urban water management and the impacts of those ICTs on the quality of life of citizens–including socio-economic, cultural, and environmental aspects. In this sense, the definition combines the use of smart technologies with the results of their use, which concerns not only a city's technological prowess, but also wider aspects of economic efficiency, social equity, and environmental sustainability. In addition, the definition stresses the importance of adequate water management for the development of cities. Smart Water Cities develop thanks to a supportive institutional, regulatory, and policy framework.

Furthermore, in a Smart Water City, ICT-based intelligent technologies complement and improve existing infrastructure and technologies for water management within the whole urban system. They are a supportive tool for the different functions of water in urban settings. This understanding highlights that Smart Water Cities concern not only the provision of drinking water and sanitation services for urban water users, but also other urban water functions such as urban water restoration, waterfront usage, and integrated water managements (see Box 3).

Box 3. Definition of a Smart Water City

"A Smart Water City is a sustainable city with contactless, intelligent water management for all"

A Smart Water City improves the quality of life of citizens by solving existing urban water problems based on various technologies and ICT technologies throughout the urban water cycle. It provides not only individual solutions for conventional water management, such as drainage, water treatment, and wastewater treatment. It also improves comprehensive water management through the restoration of urban water cycle, waterfront usage, and intelligent water management.

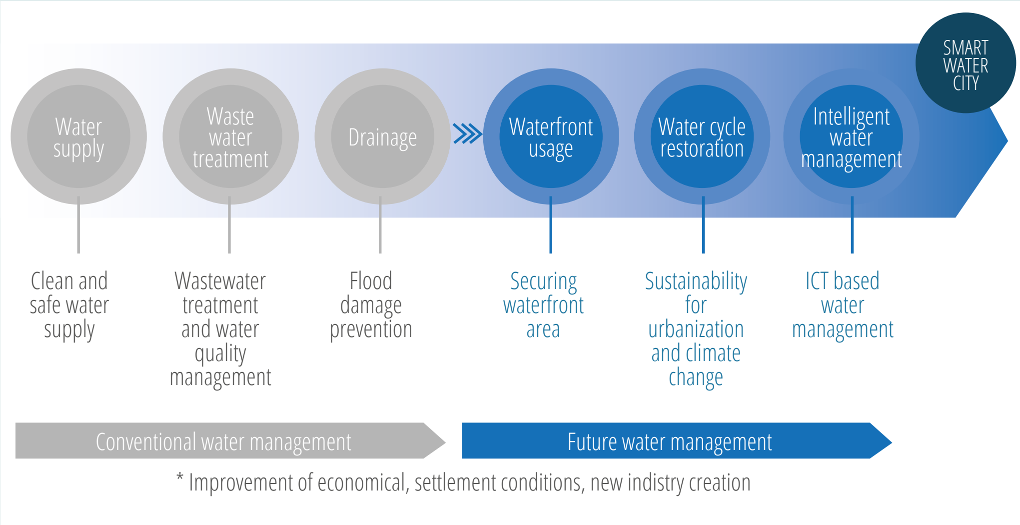


Figure 10. Components of a Smart Sustainable Water City

2.3. National and local policies and strategies for Smart Water Cities today

This section examines some of the national and regional policies and strategies put in place in the nine case study cities presented in the Annex of this report. These cases demonstrate attempts to implement smart water solutions and the Annex provides illustrations of the regulatory measures, the national plans, the economic instruments, and the voluntary means, etc., adopted in different cities to limit the need for new water resources and to optimize the available ones in different places around the world. The cases show that, in addition to having the knowledge and capacity to develop and implement technical solutions to urban water challenges, policies and strategies need to be in place to enable the adoption of smart water solutions. Having an appropriate regulatory framework is a requisite for adopting initiatives conducive to sustainability and smart development. Adequate economic resources are also crucial for the economic viability of the smart initiatives. Developing appropriate administrative capacity is also crucial for making decisions concerning water resources. In this sense, developing Smart Water Cities does not only depend on having the adequate technology in place, but also on removing non-technical obstacles and putting in place policy measures to enable their adoption.

Algarrobo (Spain)

The case of Algarrobo, in Spain, presents a successful smart city local initiative led by a private company within a facilitating national and regional regulatory framework. The case study looks at the implementation of smart water technology for the treatment and reuse of reclaimed urban waters in an area where finding alternative sources of water is of high strategic value. In this sense, the Spanish case shows the importance of establishing a regulatory framework where local initiatives can prosper. Such framework, although not dealing directly with the development of smart water technologies, has facilitated the adoption of innovative practices for water reuse and wastewater treatment initiatives. It has reduced potential obstacles that this initiative could have otherwise found. In particular, the case of Albarrobo shows a close alignment between European, national, regional, and local strategies to favor the introduction of innovative solutions for water reuse.

At the European level, the Water Framework Directive (Directive 2000/60/CE) establishes that all water bodies in the EU must achieve good qualitative and quantitative status–measured with a series of pollutant limits–while the

Urban Wastewater Directive (Directive 91/271/EEC) sets the obligation to treat wastewater "whenever appropriate". More recently, Regulation 2020/741 has established a series of minimum requirements for the reuse of water, which supports the implementation of initiatives for the safe reclaim and reuse of wastewater throughout the EU.

To meet these EU requirements, the Spanish government adopted the National Plan for the Reuse of Reclaimed Water. This plan aims to achieve "zero discharge" into coastal areas by providing incentives for the use of reclaimed water in inland areas and promoting good practices. The Spanish Circular Economy Strategy joined these efforts and proposed a complimentary goal of achieving a 10% improvement in the efficiency in the use of water, and in the Circular Economy Action Plan 2021-2023, where water reuse is considered a priority area. For its part, the regional level has adopted initiatives aiming to deal with the region's water scarcity while simultaneously facilitating access to water for irrigation–one of the pillars of the regional economy. Different regional policy strategic plans, such as the Andalusian Pact for Wate, the Andalusian Circular Bioeconomy Strategy, and the Andalusian Climate Change Law, seek to widen the use reclaimed water and to implement innovative agricultural techniques that are better adapted to climate change, more efficient in the use of water and energy, and which depend less on the use of fertilizers.

Busan Eco Delta City (Republic of Korea)
Korea was the first country in the world to enact legislation on smart cities, beginning in 2008. While the project to develop the BEDC date of 2012, the origins can be traced to 2008 when Korea has been the first country in the world to enact legislation on smart cities. After the adoption of the Act on the Construction, etc. of Ubiquitous Cities (U-City Act) in 2008, the Act on the Promotion of Smart City Development and Industry (Smart City Act) was incorporated in 2017, showcasing 34 amendments to the original act. The Smart City Act defines a smart city as 'a sustainable city wherein various city services are provided based on city infrastructure constructed by converging and integrating construction technologies, ICTs, etc. to enhance its competitiveness and liveability') (Article 2, Paragraph 1). With this Act, smart cities in Korea are considered a "platform to improve the quality of life for citizens, enhance the sustainability of cities, and foster new industries by utilizing innovative technologies of the 4th Industrial Revolution (4IR) era" .

The scope of actions for the smart cities in Korea has evolved continuously. In the early 2000s, only ICT-based infrastructure projects in new town developments were considered smart city projects (see Table 6). ICTs were seen as a main driving force of economic growth. Installing communication networks and Integrated Operation Control Centers (IOCCs) for data was led by the Ministry of Land, Infrastructure, and Transport (MOLIT). Later, the perspective on smart cities was expanded to integrate existing infrastructure and services, and smart city projects were implemented in existing cities as well as in new towns. The central government was still the main facilitator of these projects, but more ministries other than the MOLIT were involved in development, such as the Ministry of Science and ICT (MSIT) and the Ministry of Trade, Industry, and Energy (MOTIE).

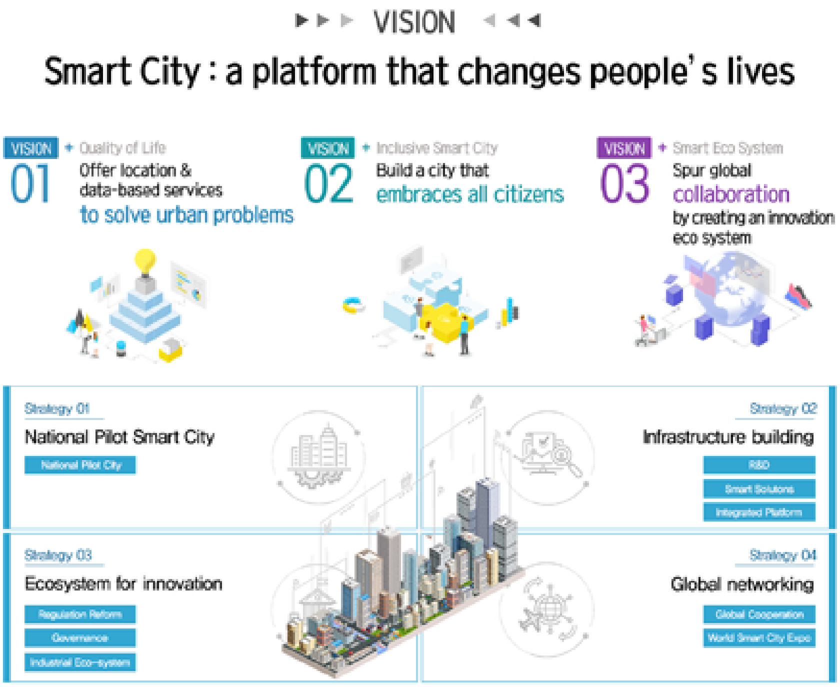
Table 6. Smart City Development in the Republic of Korea

Stage	Construction stage (2003-2013)	Connecting stage (2014-2016)	Enhancement stage (2017-present)
Goal	To create new growth engine by combining ICT with construction industry	To provide high quality service by integrating existing infrastructure and service	To solve urban problems and create innovative jobs
Information	Vertical information integration	Horizontal information integration	Cloud based information integration
Platform	Closed platform	Public platform (open to relevant organizations)	Open platform (open to private sectors)
Legal framework	Act on the Construction, etc. of Ubiquitous Cities	Act on the Construction, etc. of Ubiquitous Cities	Act on the Promotion of Smart City Development and Industry
Main agent	MOLIT	MOLIT, MSIT, MOTIE	Smart city governance
Target	New towns	New towns, existing cities	New towns, existing cities, declining cities
Projects	Integrated Operation Control Centers, physical infrastructure	Smart city platform, service integration	National smart city pilot projects, smart city platform, smart city R&D, smart city Challenge (for existing cities), smart urban regeneration (for declining cities)
Resource	Profits from residential district development projects	Government budget	Government budget, resource from private sectors

Source : OECD, 2020a.

More recently, with the adoption of the Smart City Act in 2017, the paradigm on smart cities has shifted once again. While the earlier U-City Act was more interested in the smart city construction, the latter Smart City Act brought more attention to smart city promotion and to tackling urban challenges and creating and fostering smart city-based ecosystems. Accordingly, the central government has encouraged local governments and the private sector to engage with smart city projects. It has also provided active policy support such as through financial investment and regulatory facilities. Consequently, as of 2019, 78 local governments now run dedicated organizations for smart cities, and 67 local governments are participating in the central government-supported smart city projects (MOLIT, 2019). The 3rd Smart City Comprehensive Plan (2019-2023) has been adopted which provides medium and long-term roadmaps for smart cities that aspire to change citizens' lives with better quality, more inclusive, and smarter cities (see Figure 11).

Figure 11. The 3rd Smart City Comprehensive Plan (2019-2023) in the Republic of Korea



Source: MOLIT (2019)

One of the pillars of the 3rd Smart City Comprehensive Plan is the National Pilot Smart City strategy, announced by the Presidential Committee in 2018 on the 4th Industrial Revolution (PCFIR). This strategy involves building two new towns in the cities of Sejong and Busan to serve as a test bed for smart city technologies, including 5G, AI, blockchain, etc. (See Table 7). BEDC is to focus on smart water resources and smart water service provision, thus becoming an environmentally friendly waterside city that introduces smart technologies capable of meeting and improving urban performance on the water sector. BEDC will feature new technologies such as smart water supply, hydrothermal energy, and eco-filtering. In addition, the BEDC is to provide a smart city technology "sandbox," supporting the increased development of start-ups and job creation in new growth industries.

Table 7. Overview of the National Pilot Smart City in the Republic of Korea

National Pilot Smart City	Sejong 5-1 Living Area	Busan Eco Delta Smart City
Location	In Sejong Special Self-Governing City	In Busan Metropolitan City
Area (km^2)	2.7	2.8
Population	22,500	8,500
Innovation area	Mobility Healthcare Education Energy Governance Culture Job	Robot Learn, work and play Smart intelligence **Water** Energy Education & living Healthcare Mobility Safety Park

Source: MOLIT (2019).

The BEDC is a case study where political authorities have been explicit about their objectives to develop comprehensive smart water initiatives for dealing with water challenges. In this case, efforts and resources have been mobilized at the national level to plan and implement full Smart Water Cities.

Ciudad Juarez (Mexico)
Ciudad Juarez is a city situated in the state of Chihuahua (Mexico), in an area facing a critical problem of overexploitation of aquifers in a semi-desert environment. An increase in the demand of water for both urban and agricultural use is putting water access at risk for today's and for future generations. Conscious of this problem, the Chihuahuan government launched an open consultation procedure in 2016 to discuss a common water strategy for the state which would deal with topics such as the overexploitation of aquifers, coverage of drinking water service, water quality, treatment and reuse of treated water, climate change, rainwater management, governance, climate change, and agricultural water consumption.

Based on the above, the State Water Plan 2040 (PEH 2040) was prepared in the state of Chihuahua. It was an unprecedented and unique effort in Mexico, which included six objectives for sustainable use of water in the next 25 years. Such aims include to:

- guarantee the water security of the state of Chihuahua;
- encourage the rational use of water in agriculture;
- strengthen the utilities;
- encourage governance and governance in the water sector;
- reduce the risk of meteorological phenomena to the population; and
- promote education, research, and innovation in water issues.

These 6 objectives include 8 strategic projects and 654 specific actions, requiring a total investment of 69,707 million pesos (3,485 million USD) for the period of 2019 to 2040. Among these strategic projects is the introduction of intelligent measurement and pressure management devices. Included in the Annex is the case of Ciudad Juarez, an example of how smart water initiatives develops as a tool within a larger policy framework that looks comprehensively at water challenges.

Heredia (Costa Rica)
The case of Heredia is similar to that of Algarrobo in Spain. It shows how the national regulatory framework has put in place smart urban initiatives to meet the standards and requirements of its legal water framework. The country has adopted a National Drinking Water Policy for the period, 2017-2030. One of the guidelines is the rational use of drinking water. It states that water sources must be supplied efficiently, using appropriate infrastructure and technologies to ensure their sustainable use. Likewise, the current national water policy from 2009 also presents strategic guidelines for water bodies to maintain their potential supply. In addition, the 2008 National Plan for the Comprehensive Management of Water Resources, which is still in force, works to promote efficient water use, as expressed most recently in the drafted National Drinking Water Policy as one of its guiding principles. Both the national water policy and the national plan for integrated water resources management are in the process of being updated.

However, even though current policy and planning instruments recognize the importance of adequate infrastructure and technologies, this is not reflected in specific incentives for the development and implementation of innovative technological solutions in Costa Rica. Some efforts to create incentive mechanisms for the management of watersheds have been established, allowing drinking water operators and other entities involved in water resource management to have access to the financial resources necessary for implementing these innovative technologies; however, improvements are needed to ensure that smart water technologies are more widely implemented.

Hong Kong (China)

As one of the two Special Administrative Regions established by China's central government in the late 1990s, Hong Kong is promised a high degree of autonomy under the "One-Country, Two-Systems" framework. Since 1997, Hong Kong develops its own policy approach to managing a range of social, political, economic, and environmental policy matters, including those pertaining to urban water resources management. Thus, unlike the rest of the country where local authorities would take cues from national policy frameworks in formulating their respective local-level regulatory measures, Hong Kong is given a relatively free hand to conjure its own strategy, policies, and programs for managing its water resources.

The first formal decision to apply smart technologies to managing the city's urban infrastructure and amenities could be traced to the promulgation of the "Smart City Blueprint for Hong Kong" in 2017. According to this Blueprint, 76 initiatives were launched, under six policy areas, to address the challenges of city management and improve people's livelihood through innovation and technology ("Smart Mobility", "Smart Living", "Smart Environment", "Smart People", "Smart Government", and "Smart Economy"). Officially, as pointed out by Hong Kong's Chief Executive's in her 2020 Policy Address, "smart city development aims at allowing the general public to better perceive the benefits of smart city and I&T in their daily lives". In late 2020, the Hong Kong Government released the Smart City Blueprint for Hong Kong 2.0, which contained more than 130 smart city initiatives.

The application of smart technologies for managing urban water resources is exemplified by Hong Kong's water agency—the Water Supplies Department (WSD)—to build a Water Intelligent Network (WIN) to reduce leakages from its water distribution network. To help it tackle the problem of water loss and the impact to its water supply network, the WSD, since the mid-2010s, has been configuring its 8,000 km-long water pipes into 2,400 District Metering Areas (DMAs) for monitoring and detecting leaks. The implementation of WIN could help WSD to identify DMAs that are showing higher degrees of anomalies in their flow rate data and thus, need to be given a higher priority in receiving follow-up actions such as repair, rehabilitation, or replacement.

Mumbai (India)

Applications of smart water technologies in Mumbai can be traced back to the early 2000s. The Sujal Mumbai Abhiyan program (2007) and the Automated Meter Reading (AMR) project in 2009 are two important locally-

led initiatives that intended to map Mumbai's water infrastructure and to implement measures such as water supply augmentation, alternative sources, leak prevention, water recycling, management, and citizen participation, respectively (Desai & Raj, 2012).
More recently, however, India has witnessed a top-down push for smart city development through the evolution of national level schemes aimed at urban development. The Jawaharlal Nehru National Urban Renewal mission (JNNURM) and the subsequent 5-year Smart cities mission (SCM)–both implemented through the Ministry of Housing and Urban Affairs–have played a major role in promoting and funding the development of smart cities. The JNNURM has targeted the rejuvenation of cities and towns across India between 2005 and 2015 (Ministry of Housing and Urban Affairs, 2021) and promoted the use of IT in projects which included water supply and sewerage (Sethi, 2012). These initiatives concerned greenfield cities exclusively, and aimed to attract foreign investments, technology firms, and private real estate companies (Roy, 2016; Prasad & Alizadeh, 2020). The SCM reframed the concept of Smart Water Cities to include, as well as greenfield, brownfield and pan city development projects. It aimed to help establish a total of 100 smart cities and towns in India. These projects would be co-funded by governments at different levels as well as external funding from financial intermediaries, multilateral organizations, private sector, etc. (Aijaz, 2021). The projected smart cities have sought to integrate technology in a more efficient way to create liveable, inclusive and sustainable cities (Aijaz, 2021; Prasad & Alizadeh, 2020).

However, the implementation of these plans has been inadequate for various reasons. As the Mumbai case study shows, lack of participatory planning, deficient coordination between citizens and government, and inadequate monitoring mechanisms have been present. Recent assessments of the SCM show that only 50% of the project has been completed which can be linked to the difficulties of states and union governments to mobilize necessary funds (Aijaz, 2021). Cost recovery through service charges has been opposed for fears of inequitable development (Aijaz, 2021; Housing and Land Rights Network, 2018). Concerns about the sustainability of these projects have been raised (Roy, 2016; Prasad & Alizadeh, 2020). Local politics has also influenced the implementation of these national plans, as local authorities have resisted what they perceived to be an erosion of municipal authorities' powers (Aijaz, 2021). The Mumbai case shows that the successful implementation of water ICTs requires more than technological prowess; it requires an adequate institutional and decision-making framework.

Nakuru (Kenya)
The Nakuru case study presents an initiative to address both floods and water scarcity, via the adoption of a sponge city project. The case shows how urban water policies are strongly connected to other local initiatives – in this case, urban planning and land use policies. Thus, successful implementation of measures to deal water challenges is strongly connected to and, at times, dependent of, a different set of local initiatives, institutions, and actors. The water system is interconnected to other areas that might influence the success or failure of water sector initiatives.

The case study follows the development of a water policy initiative in the rapidly growing city of Nakuru (Kenya). Population growth is causing the expansion of city-slums, increase in water demand, and difficulties to supply water to 100% of the residents in these cities. To deal with the challenges of population growth, the Kenyan government has adopted the national strategy, 'Vision 2030' (The Ministry of Planning and Devolution, 2007), which has prioritized management of urbanized areas as one of the development strategies in the country. Vision 2030 aims to enhance the provision of high quality of life for all citizens in a clean and well secure environment, including access to adequate water resources. Deriving from this strategic plan, the government has aimed at facilitating and enhancing sustainable urban development through the adoption of an Integrated Urban and Regional Planning Management Framework of the towns/cities. In addition, the National Urban Development Policy (NUDP) and the National Land policy both aim to enhance sustainable urban planning and management of natural resources through governance and delivery of accessible, quality, and efficient infrastructure and services. The Urban Areas and Cities Act has sought to provide different criteria on development and to establish urban areas that make use of social inclusion of its residents. The Integrated Urban Areas and City Development Planning Management Framework has emphasized ensuring quality delivery of various services such as water provision, solid waste management, and good health of its residents (Government of Kenya, 2012). The Kenya National Adaptation Plan (NAP) 2015-2030 and the National Climate Change Action Plan 2018 to 2022 looks at urban adaptation strategies and innovations for climate change including control of flooding and promotion of green infrastructures (Republic of Kenya, 2016). Addressing the challenges of water resources management in the country has been considered not in isolation but in connection with larger land development and urban management policies.

The actual implementation of these policies has been, however, deficient, and has negatively impacted the success of water initiatives like the Nakuru Sponge City Project. Poor urban planning practices and poor environmental management make it difficult to provide adequate water services to the population. Limited technical and institutional capacity within the various departments and ministries in sustainable urban planning and a reduced number of stakeholders/actors engaged in implementation and management of sustainable urban development have also contributed to these difficulties.

New York City (United States)
The New York City case study illustrates how the implementation of smart water technologies has complemented other policy measures to meet the city's objectives for water resources management. Indeed, the local water policy makers have seen water ICTs as tools along with other policy options, such as the construction and upgrade of green and grey water infrastructures and improving the existing pollution control strategies.

In the United States, the Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into waters and regulating quality standards for surface waters. In 2010, with the adoption of the Green Infrastructure Plan, New York City developed a detailed framework and implementation plan to meet the twin goals of better water quality in New York Harbour (in line with the CWA standards) and a liveable and sustainable New York City.

The plan identified source control and the development of integrated green infrastructure as central strategies to ensuring compliance with the CWA. This plan led to the launch of the New York City Green Infrastructure Program, which has implemented over 10,000 green infrastructure practices and managed over 1,200 "greened acres" constructed or currently in construction at the time of this report. Over the last several decades, the city has invested more than 45 billion USD in the construction and upgrade of critical wastewater and drainage infrastructure. In recent years, the city has committed an additional 10.6 billion USD investment in environmental protection for its water bodies. Smart water technologies have been employed in several projects, as indicated in the Annex, with the purpose of providing more accurate information on water status, i.e. water quantity and water quality. These initiatives have served to complement existing approaches that control pollution, drainage, and flood risks.

Changing climate, population growth, aging infrastructure, limited resources, and increasingly complex water quality issues have led the New York City authorities to new approaches for achieving legal and policy requirements. New York City has been actively engaging with other cities that have experienced extreme rain events to exchange knowledge and develop innovative solutions to prepare for more and heavier downpours, or cloudbursts, brought about by climate change. At its core, the city continues to seek solutions that integrate watershed, water resources, and water facilities management in a more holistic manner. The use of water ICTs is considered a complementary approach to this vision.

Ningbo (China)
Ningbo, a city situated in Eastern China, suffers from flood risks. The Chinese have chosen to develop pilot cities in Ningbo to test smart water technologies and SWM practices, to boost and support the modernization of water infrastructures, and to control flooding. These technologies include the use of remote sensing, big data, and 5G. Ningbo is also testing SWM practices to improve coordination, service efficiency, and for other innovative work practices. The Ministry of Water Resources, in charge of the implementation and operation of water ICTs in the pilot cities, has established the principles that rule over the Smart Water City plans. They include:

1. Evidence-based, problem-oriented planning. Smart city plans analyse status, detect resources and data needs, identify challenges and obstacles to defining and achieving realistic and feasible goals, and to prioritize which obstacles to address first.
2. Innovation and Creativity. Smart city plans promote the innovative application and integrative use of new technologies, such as Internet of Things, remote sensing, big data, artificial intelligence, 5G, blockchain, and more.
3. Cooperation and data sharing. Smart city facilitate relevant real-time information on infrastructure and shares resources with all relevant actors.
4. Evaluation, replication and upscaling. The Ministry of Water Resource is keen to evaluate the results of these initiatives and examine what positive outcomes can be up-scaled and replicated nationwide to achieve efficient and beneficial development of SWM in China.

Overall, the cases show two different national and local policy approaches to the implementation of innovative water technologies. BEDC and Ningbo have been pilot projects supported by the national governments. Their developments have served to test innovative water technologies as well as potential solutions, and to learn from them in order to apply them in other places and circumstances. In all other case studies, technologies have been employed, with more or less success, to reach policy objectives regarding the environment, water services provision, and/or urban planning. In these cases, water ICTs have been considered a vital tool for fulfilling local objectives. The cases in the Annex demonstrate this, illustrating several factors that have impacted facilitation or adoption, be it an adequate institutional framework, economic resources, appropriate administrative capacities, etc. This shows that the successful implementation of smart water technologies goes beyond technological knowledge and capacities.

2.4. Smart water technologies in world cities today

Smart technologies are developing rapidly around the world, providing an evolving group of innovative and integrated solutions for urban challenges. They are creating a new area of development for a new industry with large economic incentives and opportunities for growth. Some estimates refer to a global market potential of 651.7 billion USD for the smart city market by 2028 (Adroit Market Research, 2022).

In the water sector, ICTs uptake has been slower than in other sectors, but policy makers and the industry are paying close attention to smart technologies for both water resources management and water services provision (Leflaive, et al, 2020). Devices such as smart pipes and sensor networks that detect and measure water strain, temperature, and pressure anomalies, as well as smart meters to measure consumption, membranes, and cloud computing to share information, and smart materials that improve water infrastructure and mechanisms, etc., are among the devices designed and manufactured to help deal with urban water challenges. With demands for water projected to grow dramatically –up to 1% per year in all sectors (UNESCO & UN-Water, 2020)– these advanced technologies play a vital role: they can provide real-time, automated data on water quality, water use, and its consumption, as well as the functioning of the infrastructure, etc., which could contribute enormously to resolving pressing water challenges linked to climate change and demographic shifts.

Some key technologies have been put in place to improve the quantity and quality of water resources available in cities, to manage urban water risks and their potential impact, and to enhance water urban services provision. The Annex details several city case studies which highlight these technologies and which provide evidence of how ICTs are helping water service providers deal with urban water challenges, whether they are floods, water scarcity, deficient water quality, aging infrastructure, and/or inadequate urban planning. Smart solutions are contributing to more efficient management of water resources.

Indeed, water technologies have been used to improve the response to climate change and extreme weather events in cities. With flooding risks, sophisticated equipment has been put in place to monitor the status of water bodies and to provide warnings about rapid changes in storage, and to communicate this information in real time. This technology allows water authorities, as well as citizens and organizations, to have the most up-to-date information and to prepare for any potential water disaster. This pioneer technology has been put in place in the pilot project of the city of Ningbo (China), which faces large flood risks. The local government has adopted a plan to introduce innovative smart water technology to monitor water levels and produce a warning system that allows the authorities prepare in advance against floods. In New York City (USA), the department in charge of environmental protection has led a series of interventions that work to limit the volume of stormwater entering the city's sewer system. These interventions include plans to introduce green infrastructures, public and private properties retrofits, and new pilot drainage systems. ICTs have also been extensively employed in the city planning and urban expansion to restore the natural water cycle. Together, these integrated water management initiatives strive to ensure that the city can manage large volumes of water in future storms and flooding events, limiting their potential damage.

ICTs have also been employed to confront water scarcity. Smart metering has been a key ICT strategy to limit water misuse in many cities around the world. It is estimated water metering can achieve reductions of approximately 15% in higher-income cities. In developing cities, where baseline residential consumption is lower to begin with, savings are more modest but also considerable (Woerzel et al., 2018). The objective of the installation of smart meters has been to track water consumption and to give fast and reliable digital feedback messages to the water service provider and/or the consumer on the amount of water employed. Water tracking has helped to detect water losses, increase awareness on water consumption, and nudge people toward water saving measures. Ciudad Juarez in Mexico, Mumbai in India, and Hong Kong in China are cities that have introduced smart metering. The technology employed has been different, but the objectives have been similar in that they aim to reduce water consumption and save water. Water metering in these two cases has also been particularly useful for identifying problems in aging

infrastructure, as it has helped to find leakages and detect low or irregular pump pressure, thus optimising the repair and replacement of old infrastructure and prompting action when incidents have been identified.
To deal with water shortages, some cities have also developed the means to increase water storage, retention, and recharge, to supply water for domestic and industrial uses at times of needs. In the Annex, we can see the case of Nakuru (Kenya), where a project to harvests excess water and to enable water storage for periods of drought has been planned. Nakuru shows how ICTs have been employed to involve residents in decision-making processes to map out problems and propose solutions.

Smart technologies are also employed to reduce the need for new fresh water supplies by using reclaimed water (wastewater/grey water) for meeting local water demands. A growing recognition of the value of this resource is broadening the scope of its application: urban and peri-urban agriculture, irrigation of golf courses, parks, residential properties, highway medians and other landscaped areas, toilet flushing, car washing, etc. A good case for this is in the municipality of Algarrobo (Spain), where smart technologies have been adopted to reclaim urban wastewater for agriculture irrigation and fertilization. The implementation of this technology has had a positive environmental impact by reducing the demands on already stretched local water bodies, promoting local economies, and facilitating job creation.

Water technologies have been used to improve deficient water quality. In many countries, devices such as automated sensors have been used extensively in pollution sampling points across freshwater and drinking water sources to monitor, collect, and share information about the status of water. These ICTs have served both public health and environmental protection objectives, prompting fast action when pollution incidents have been identified and thus avoiding damages endangering water bodies and water-dependent ecosystems. In this report, we can see the case of Heredia (Costa Rica), where innovative technology is providing the treatment necessary to make surface, turbid waters safe to drink. The technology is employed to monitor water quality, collect water sediments, and identify poor drinking water status.

The solutions that technologies provide do not stop there. BEDC, which is being built in a district in the city of Busan (Republic of Korea), plans to create the conditions for testing a large variety of technologies to deal with water challenges at different stages of the urban water cycle. This innovative approach to urban water planning practices seek to deal with water challenges at different stages of the urban water cycle, increasing ecosystem resilience and harmonizing human life and nature. The urban development plan for the city puts integrated water management and ICTs at the core of future expansion of the city. The plan serves both public health and environmental protection objectives. Technologies to monitor, purify, distribute, use, and reuse water within the city with great precision are expected to make it possible to protect the environment, improve water quality, respond timely to flood risks, fight urban heat island, treat waste water, etc.

All these different initiatives provide evidence of how smart policies and technologies have helped to deal with current urban water challenges in different cities and in different circumstances. They have shown the

improvements achieved in urban water services provision and have suggested promising venues for future technological and policy developments.

While information on smart practices is essential, knowledge is still inconsistent with regards to the impact of ICTs on the urban water system. Although illustrative, case studies tell us little about the conditions to export solutions from one city to another. In addition, they are limited in how they single out areas for improvement and do not aid in defining appropriate levels for urban water performance. When the local circumstances and challenges are so diverse, replicating and scaling up or down is a complex matter. As a result, certain key questions remain unanswered:

- To what extent are water technologies delivering against the far reaching, current, and future urban water challenges?
- To what degree is the implementation of smart water technologies creating "Smart Water Cities"? When does a city that implements ICTs in the water sector become a "Smart Water City"?
- Can we identify different degrees of "smartness" in a city, with areas where progress has been made and others where progress is still lagging?

These questions highlight the need to develop an assessment method capable of examining and benchmarking cities so that we can evaluate how smart water systems are. Such analysis should tell us about the different functions of water in urban settings, about how and to what degree the proposed smart solutions address those functions, and whether these solutions are sufficient and adequate enough so that their implementation can qualify cities as a "Smart Water City". This assessment method can help to identify the elements that facilitate the implementation of smart and sustainable water solutions in cities. It can also help to identify the barriers that policy makers and water professionals are likely to face, thus becoming a valuable guidance for cities.

PART 2

GLOBAL STANDARDS, INDICATORS, AND CERTIFICATION SCHEMES

Part 2 of the report examines how global standard indicators and certification schemes operate and details what we can learn from them. Doing so sets the foundation for the development of a future Smart Water City standard and certification scheme in later stages of this project.

This part is divided into two chapters: Chapter 3 defines what global standards indicators and certification schemes are and identifies their characteristics. This chapter helps us to distinguish the different topics that performance indicators can aim to measure and how best to do it. Chapter 4 analyses in detail eight relevant standards and certification schemes measuring sustainable development and/or water resources management in urban settings. Standards elaborated by international organizations are distinguished from those developed by the private sector, non-governmental organizations, and by academia. The chapter explains the indicators and sources of information that each standard employs and, when appropriate, its certification process. The chapter concludes with a comparison of these standards, setting the groundwork for future development of a Smart Water Cities standards and certification scheme.

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CHAPTER 3
DEVELOPING STANDARDS: CONCEPT AND MEASUREMENTS

3.1. What are standards and what do they measure?

Measuring performance has been a longstanding aim of human activity. Evidence exists of the attempts to measure workers and employees' performance as far back as the Middle Ages. With the introduction of modern methods of mass production in the 20th century, such as specialization of labor and the introduction of tools and machinery, organizational management became more complex and structured, and with it, the examination of performance became the subject of a robust discipline (See Kuske & Zander, 2005). From this, we have gained substantial knowledge, experience, and best practices for measuring human activity.

Standards serve to measure performance. They define the characteristics of a product, a process, or a service, including its different constitutive elements, its safety aspects, and performance requirements, etc. Standards may apply to the specific and mechanical functioning of new technologies, but they may also apply to more comprehensive products, services, procedures, etc. They are developed to measure a particular product or service and to establish how those services or products meets certain requirements. These requirements may be legal obligations without which a product or service cannot be offered to the public, or voluntary, serving to establish if a certain product meets specific criteria. By doing so, such standards facilitate the evaluation of how different products and processes work and set benchmarks to compare between alternative products and processes.

In certain cases, a product, service, or system that meets the requirements of a standard is given assurance by an independent certification body.

To issue a certification, the certification body examines whether the applicant (usually a manufacturer or a service provider) meets the established criteria, and depending on the results, decides whether to award the certification. Thus, certifications guarantee that a product or service has certain qualities. Frequently, the certified manufacturer or service provider displays the certification symbol on its product as a mark of distinction or as proof of achievement. This provides users and consumers with extra information on the product's characteristics and helps the certified organization to distinguish itself from its competitors.

To develop standards, it is necessary to define what elements of a product or service are worth measuring. Different approaches exist to doing so. The input-


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process-output-outcome-impact typology, used by UN bodies, is particularly helpful in defining what different aspects of a program, strategy, or project can be measured (UNISDR, 2015):

INPUT → PROCESS → OUTPUT → OUTCOME → IMPACT

• ***Input indicators*** refer to the resources needed for the implementation of an intervention, a product, or a service. Input indictors measure the quantity, quality, and timeliness of resources employed. Elements such as financial resources, time, staff, expertise, methods employed, materials, etc. are all examples of input indicators.

• ***Process indicators*** measure whether planned activities and milestones have taken place. Examples of process indicators could include scheduled meetings that have taken place, conducting training courses, launching an information campaign, etc. In the context of a smart city, the distribution of smart meters by a certain deadline could be an example of process indicator.

• ***Output indicators*** refer to what the system produces, the activity resulting from a program, a strategy, or a policy. For example, in a smart city, an output indicator would measure the area of isolated roofs in the city, or the number of electric busses in the system, or the volume of recycled water used, etc.

• ***Outcome indicators*** measure intermediate results generated by outputs. Outcome indicators refer more specifically to the objectives of an intervention and concern meaningful changes for the population served, such as anticipated changes in knowledge, skills, attitudes, and behavior. Often, they are coverage indicators measuring the extent to which the target population has been reached. For instance, volume of water saved resulting from the implementation of certain water saving measures would be an outcome indicator.

• ***Impact indicators*** measure the results that are directly due to the outcomes of a program. They tend to operate on a longer-term basis and often concern the ultimate goals of the policy or program. They are harder to measure; establishing the causal link between the policy outcomes and their impact is not always easy. Indeed, the impact of a policy does not only depend on the measures taken, and the impact might happen or not. For instance, reducing a city's water consumption or increasing water flood protection can be impact indicators of a Smart Water City.

Recognizing the different types of approaches reveals different elements of evaluating the same product, service, or policy. Also, different measures from these different approaches can be used to track performance and have a more rounded account of how a product or service functions. Depending on what is measured, the performance of that product will likely be different in terms of its effectiveness, efficacity, timeliness, etc.

3.2. Characteristics of standards

In addition to deciding what aspect of performance to measure, developing standards involves making decisions on how best to measure performance. This task requires identifying adequate indicators capable of providing information on the performance that we wish to evaluate and monitor.

Understanding the most important characteristics of good indicators and standards can help set adequate, fit-for-purpose standards and certification schemes. These characteristics can work to examine the virtues of existing standards with critical eyes and to propose indicators and measurements that better serve objectives of developing a global standard scheme for Smart Water Cities. A seminal work by George T. Doran (1981) identified the characteristics of successful standards and presented them with the acronym S.M.A.R.T. whereby the letters stand for:

1. Specific. They target a specific and precise area of performance. This implies that standards need to be clear and well-define, and that they effectively measure the factors we want to know about. This feature is closely related to that of validity, i.e. the extent to which a measurement or test accurately quantifies what is intended to be assessed.

2. Measurable. Performance can be examined and accounted for. Standards can employ quantitative or qualitative indicators. Quantitative indicators measure performance in numbers, such as units, prices, proportions, rates of change, and ratios, etc. Qualitative indicators report performance in words: degree of satisfaction or agreement or opinion. Regardless of the type of indicator employed, all indicators should concern aspects of performance that can be effectively assessed.

3. Attainable (also Assignable). The standard measures performance that can be achieved with a reasonable level of effort under normal operating conditions. A good indicator reports on the activities of a team or cluster of teams that work together. Attainable standards assume the existence of potential accidents and typical losses that can normally happen.

4. Realistic. They state what results can realistically be achieved, given available resources. This principle is often linked to the notions of simplicity and applicability, which are key elements for indicators to be successfully employed. Indeed, on many occasions, performance indicators are administered and measured by personnel dealing with many tasks, have limited time and monetary resources. Standards should provide clear and relevant information without much reference to technical or methodological details.

5. Time-related. Indicators may employ a different timeframe for evaluation: either short-term progress evaluation or long-term impact assessment. It is important to establish a timeframe because depending on the moment when the evaluation occurs, the observations might be different. Certain effects take longer to be detectable, whereas other indicators may bring about meaningful results even at shorter and more frequent intervals.

In addition, other important characteristics of good standard have been highlighted:

6. Relevance. Relevant standards measure performance that matters. Parmenter (2015) distinguishes between simple standard indicators and KPIs. KPIs focus on the "critical performance for the current and future success of the organization". They are measures that link daily activities to the factors that are critical for an organization's success. In this sense, depending on their relevance or centrality, standards employ core indicators, which identify which key elements must be assessed in all cases, supporting indicators, which can be appropriate to measure recommended performance elements, and profile indicators, which provide context for the performance assessment.

7. Orientation. Standards can be further classified into "prescriptive" and "performance oriented". The first type provides guidance on the measures and solutions that can be applied. In doing so, they also limit the scope of the solutions that can be implemented. The second type of standard seeks to provide guidance on the final performance, leaving room for innovative solutions in design (Huovila et al., 2019). It has also been argued that that KPIs should "encourage appropriate action" in that they should ensure that they have a positive impact on performance. The objective is to avoid developing poorly thought through measures that unintentionally lead to dysfunctional behavior within organizations.

8. Revisable. Good standards need to be revisable as progress is made and certain objectives are attained. Equally, they also need to be revisable when circumstances worsen in order to provide appropriate guidance to policy makers and organizations and to aid in the improvement of deteriorated situations. In this sense, standard setting is a process, not an end result: standards help to set more ambitious targets, constantly adopting new circumstances, technologies, actors, and activities.

CHAPTER 4
ANALYSIS OF GLOBAL STANDARDS, INDICATORS, AND CERTIFICATION SCHEMES

Many standards and certification schemes dealing with urban sustainable growth and local development have been adopted in the last 20 years. The signing of the Local Agenda 21 by the UN in the early 1990s inaugurated a period when monitoring urban activity became a central activity of international agencies and organizations around the world. This chapter examines eight of those global standards and certification schemes. Analyzing the characteristics of these global standards and certification schemes provides frameworks for how the indicators and the procedures are set up, which helps to draw lessons for establishing future global standards and certification schemes for Smart Water Cities.

The eight global standards and certification schemes have been selected for two reasons:

1. The standard's topic, that is, the performance that the standard measures: all the selected standards concern sustainability, smartness, resilience, etc.
2. The standard's unit analysis: all the selected standards concern the local level, mainly understood as the city.

The selected standards have been developed both by international organizations and by non-governmental organizations and the private sector. Amongst the first are the UN, the International Organization for Standardization (ISO), and the Organization for Economic Co-operation and Development (OECD). UN has led an initiative to evaluate local policies and measures to make cities smarter and more sustainable. This initiative, called the United 4 Smart Sustainable Cities (U4SSC), has been conducted since 2016 with the ITU, United Nations Economic Commission for Europe (UNECE), and UN-Habitat. This instrument focuses on three aspects: the cities' attainment of the SDGs, their degree of smartness, and their sustainability.

ISO brings together 165 national standards official bodies as members. Since its constitution in 1946, ISO has issued over 22,000 standards and currently produces around 100 new standards each month on an array of areas, topics, and technologies. Sustainability and smart development features vary greatly in ISO standards production. ISO 37120 Series on Sustainable Cities and Communities, a set of three standards concerning urban sustainability (ISO 37120), smartness (ISO 37122), and resilience (ISO 37123), is examined.

The OECD is an intergovernmental organization founded in 1961 to stimulate economic progress and world trade. The OECD has undertaken research and analysis for international comparison for its 38 member countries and beyond. Their publications help to define the criteria and indicators used to examine and measure a wide variety of products, services, and policies. The OECD's work on smart cities is examined by focusing on the OECD Smart City Measurement Framework.

Amongst non-governmental organizations and the private sector which has elaborated on standards and certification schemes for smart and sustainable water cities, five standards were selected. The organizations behind the CITYKeys Smart City Index assessment framework and the LEED for Cities and Communities standard have focused on measuring sustainable city practices, including but not limited to water resources management. The other three standards–Arcadis Sustainable Cities Water Index, KWR City Blueprint Approach, and AWS International Water Stewardship Standard–have paid attention to water resources management.

As a research project funded by the European Union's Horizon 2020 program, CITYKeys Smart City Index was developed by a consortium of European universities and research centres. It validated KPIs and data collection procedures for examining and comparing smart city solutions across European cities. Its detailed analysis deserves full attention in this report.

The U.S. Green Building Council (USGBC) and the Green Business Certification, inc. (GBCI) are behind one of the better-known standards and certification schemes for sustainable cities: the LEED for Cities and Communities. The USGBC is a not-for-profit organization advocating for sustainable building practices which has developed the LEED indicators and procedures. The GBCI is an organization that provides third-party credentials and verification for the LEED standard.

Arcadis and the Centre for Economics and Business Research (CEBR) are two private consultancies operating globally from their headquarters in the Netherlands and the UK, respectively. They have developed the Arcadis

Sustainable Cities Water Index, which seeks to assess and rank the urban water management of cities around the world.

KWR City Blueprint Approach is a tool to examine Integrated Water Resources Management (IWRM) in cities. This index has been prepared by KWR Water Research Institute, an independent research center based in the Netherlands. The City Blueprint Approach provides a methodology for diagnosing how cities around the world ensure an integrated management of their urban waters.

The Alliance for Water Stewardship (AWS) is a membership-based association bringing together businesses, NGOs, and the public sector. The AWS seeks to promote local water resources sustainability through the adoption of a standard and certification scheme, the International Water Stewardship Standard, or the AWS Standard.

The following pages examine each of the standards in depth. For each global standard, we analyze its main characteristics, including what they measure and how they do so; and if a certification of the standard exists, we analyze main characteristics and its procedure for certification. In following the Global Standard, the elements analyzed are as follows:

1. **Standard topic** reflects what performance the standard aims to measure, such as sustainability, smartness, resilience, or other, as well as its scope of application–the city, the community, water basins, or other sites.

2. **Standard categories** reflect the subject of a standard, broken down into a series of elements for measuring, which may consider sectoral policies, stages of implementation, or other.

3. **Standard indicators** are the elements that serve to examine and measure performance. They derive from observed facts and phenomena.

4. **Standard metrics** concern the unit of measurement employed by the standards.

When a certification scheme exists to accredit one of the examined standards, four further aspects are analyzed:

1. **Certification organisation** refers to the organizations examine and issues the certification.

2. **Certification applicant** concerns the organization or actor that can apply for the certification. It asks if they are public or private organization, a regional authority, a city, or its neighbourhood.

3. **Certification process** refers to the procedure that the applicants must follow to receive a certification.

4. **Type of certification** concerns to how long the validity period of the certification is. It asks if certifications are graded according to the grade achieved and if there is a minimum mark to be awarded a certification.


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4.1. International organizations

4.1.1 United 4 Smart Sustainable Cities

The United 4 Smart Sustainable Cities (U4SSC) is a United Nation initiative coordinated by International Telecommunication Union (ITU), United Nations Economic Commission for Europe (UNECE), and UN-Habitat. Launched in May 2016, this instrument examines the cities' attainment of the Sustainable Development Goals, their degree of smartness, and their sustainability.

1. Standard topic
The U4SSC seeks to provide a methodology to measure the smartness and sustainability of cities around the world. The initiative aims to enable cities to measure their progress over time, compare their performance to other cities and allow for the dissemination of best practices at the city level.

2. Standard categories.
The standard establishes three dimensions – Economy; Environmental; and Society and Culture - and seven subdimensions (ICT; Productivity; Infrastructure; Environment; Energy; Education, Health and Culture; Safety, Housing, and Social Inclusion). Each subdimension is broken down into 28 different categories (See Table 8).

"Water and sanitation" is a category that appears in three subdimensions (ICT; Environment; Infrastructure). In each of these subdimensions, different aspects of water and sanitation performance are measured, such as the characteristics of the infrastructure in the sector and its degree of environmental protection. Thus, for instance, the ICT subdivision, which is in the Economy dimension, breaks down into six categories where a city will examine the presence and use of ICTs in different sectors of the economy. These include water and sanitation, drainage sectors, as well as electricity, transport, and public sector.

Table 8. Dimensions, Subdimensions and Categories of the United 4 Smart Sustainable Cities Standard

Dimension	Subdimension	Category
Economy	ICT	ICT Infrastructure
		Water and Sanitation
		Drainage
		Electricity supply
		Transport
		Public sector
	Productivity	Innovation
		Employment
	Infrastructure	**Water and Sanitation**
		Waste
		Electricity supply
		Transport
		Building
		Urban planning
Environment	Environment	Air quality
		Water and Sanitation
		Waste
		Environmental quality
		Public Spaces and Nature
	Energy	Energy
Social and Culture	Education Health and Culture	Education
		Health
		Culture
	Safety, Housing and Social Inclusion	Housing
		Social inclusion
		Citizen participation
		Safety
		Food security

Water-related categories are shown in bold.

3. Standard Indicators

The U4SSC standard has 91 indicators: 45 in the Economy dimension, 17 in the Environment dimension, and 29 in the Social and Culture dimension. The standard employs output indicators whereby what a city "produces" in terms of economic, social, and environmental "smart" sustainability is measured.

Not all indicators have the same value. Some of them are "core" indicators and others are "advanced" indicators. Core indicators concern the basic elements that a smart and sustainable city should be able to achieve. Advanced indicators provide a more in-depth view of a city and measure progress on more advanced initiatives; however, they may be beyond the current capabilities of some cities to report or implement. 11 indicators are proposed to examine the function of the water and sanitation sector in the economy and the environmental categories. All but one of them are core indicators. They are the following:

Table 9. Water Indicators in the United 4 Smart Sustainable Cities Standard

Dimension (Subdimension)	Indicator	Definition
Economy (Infrastructure)	Basic Water Supply	Percentage of city households with access to a basic water supply
	Potable Water Supply	Percentage of households with a safely managed drinking water service
	Water Supply Loss	Percentage of water loss in the water distribution system
	Wastewater Collection	Percentage of households served by wastewater collection
	Household Sanitation	Percentage of city households with access to basic sanitation facilities
Economy (ICT)	Smart Water Meters	Percentage implementation of smart water meters
	Water Supply ICT Monitoring	Percentage of the water distribution system monitored by ICT (advanced)
Environment (Environment)	Drinking Water Quality	Percentage of households covered by an audited Water Safety Plan
	Water Consumption	Total water consumption per capita
	Fresh Water Consumption	Percentage of water consumed from freshwater sources
	Wastewater Treatment	Percentage of wastewater receiving treatment (Primary, Secondary, Tertiary)

4. Standard metrics.
The metrics employed for the indicators are all quantitative, and refer to either a percentage of the population, or a ratio per capita of the population. By doing so, the indicators allow comparisons among cities. The standard also indicates the most likely data source or relevant database where this information can be collected, which refers mostly to local water service providers but also from the WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation.

4.1.2 ISO 37120 Series on Sustainable Cities and Communities

The International Organization for Standardization (ISO) is a worldwide federation of national standard bodies dedicated to the preparation and publication of International Standards. ISO technical committees work on developing the standards, with governmental and non-governmental international organizations taking part in the work.
ISO has developed a series on sustainable cities and communities, which includes three ISO standards (ISO 37120, ISO 37122, and ISO 37123) focused on sustainable, smart, and resilient cities. These three ISO standards, known as the ISO 37120 Series on Sustainable Cities and Communities, bring over 276 different indicators to examine local policies and development strategies.

1. Standard topic.
The ISO 37120 Series on Sustainable Cities and Communities (ISO 37120 Series) consists of three ISO standards designed to assist cities in evaluating and monitoring city performance. They are as follows:

- ISO 37120 standard for city services and quality of life examines the degree of sustainability in the provision of urban services, as well as citizen's health and wellbeing.

Once a city has been awarded an ISO 37120, it can opt for ISO 37122 and ISO 37123.

- ISO 37122 standard for smart cities analyses the presence of ICTs in urban life and local services.
- ISO 37123 standard for resilient cities measures examines the extent to which cities can prepare for, recover from, and adapt to various shocks and stresses.

The standards consider sustainability as a general and guiding principle in the development of cities. Therefore, being awarded ISO 37120 standard is a prerequisite for applying to the other two standards, ISO 37122 and ISO 37123. "Smart city" and "resilient city" are considered subsidiary to adhering to the principles of economic efficiency, environmental sustainability, and social equity that ISO 37120 standard measures.

2. Standards categories.

The ISO 37120 Series identifies 19 different categories–referred in the ISO publications as themes–which correspond to services provided and activities organized at the local level (Table 10). Urban water services are present in two different categories: wastewater and water.

Table 10. Categories of ISO 37120 Series on Sustainable Cities and Communities

	Categories
1	Economy
2	Education
3	Energy
4	Environment and climate change
5	Finance
6	Governance
7	Health
8	Housing
9	Population and social conditions
10	Recreation
11	Safety
12	Solid waste
13	Sport and culture
14	Telecommunication
15	Transportation
16	Urban/local agriculture and food security
17	Urban planning
18	**Wastewater**
19	**Water**

Source: ISO 2018; 2019a; 2019b

Water-related categories are shown in bold.

3. Standards indicators

The ISO 37120 Series has developed different sets of indicators depending on the topic that they refer to:

- ISO 37120 standard consists of 104 indicators in 19 categories. Not all indicators are the same: of the 104, 45 are "core" or more relevant indicators, while 59 are "supporting" or recommended indicators; 4 core/supporting indicators belong to the wastewater category, 7 to the water category. They are mainly concerned with coverage of urban water services to the population, volume of water consumed, and supply services (e.g. leakages and interruptions).

- In addition, ISO 37120 standard has developed 24 "profile indicators" which are used for providing information to help compare certified cities. These profile indicators provide basic background information on the cities, such as population, urban density, household income, education, budget, etc., that provide context for assessing urban sustainability.

- ISO 37122 standard has 80 indicators in the 19 categories and is focused on the digitalization of the different local sectors. 4 of those indicators concern the water category and look at the use of digital water quality, water network monitoring, and the use of smart water meters. 5 indicators belong to the wastewater category and examine elements such as percentage of water reused and digital measurements.

- ISO 37123 standard consists of 68 indicators in 19 categories that examine to what extent a city is ready to adjust to multi-hazards and different stressors. The water category includes two indicators: the first concerns the number of different water sources providing at least 5% of the city's total water supply; and second concerns the percentage of city population that can be supplied with drinking water by alternative methods for 72 hours. No indicators have been developed for the wastewater category.

Table 11. Water Categories and Indicators of the ISO 37120 Series on Sustainable Cities and Communities

Category	Standard and Indicator		
	ISO 37120	ISO 37122	ISO 37123
Wastewater	Percentage of city population served by wastewater collection (core)	Percentage of treated wastewater being reused	
	Percentage of city's wastewater receiving centralized treatment (core)	Percentage of biosolids that are reused (dry matter mass)	
	Percentage of population with access to improved sanitation (core)	Energy derived from wastewater as a percentage of total energy consumption of the city	
	Compliance rate of wastewater treatment (supporting)	Percentage of total amount of wastewater in the city that is used to generate energy	
		Percentage of the wastewater pipeline network monitored by a real-time data-tracking sensor system	
Water	Percentage of city population with potable water supply service (core)	Percentage of drinking water tracked by real-time, water quality monitoring station	Number of different sources providing at least 5% of total water supply capacity
	Percentage of city population with sustainable access to an improved water source (core)	Number of real-time environmental water quality monitoring stations per 100,000 population	Percentage of city population that can be supplied with drinking water by alternative methods for 72 hours
	Total domestic water consumption per capita (litres/day) (core)	Percentage of the city's water distribution network monitored by a smart water system	
	Compliance rate of drinking water quality (core indicator)	Percentage of buildings in the city with smart water meters	
	Total water consumption per capita (litres/day) (supporting)		
	Average annual hours of water service interruptions per household (supporting)		
	Percentage of water loss (unaccounted for water) (supporting)		

4. Standard metrics

All indicators in the series use quantitative metrics. Ratios and percentages of population, labour force, customers, city areas, revenue, utility uses, budget, etc., are often employed.

Certification Scheme

1. Certification organization

ISO did not develop the ISO 37120 Series itself. The World Council on City Data (WCCD), based in Canada, led the development of these three series as well as their audit protocol, including a third-party verification and certification scheme. Moreover, ISO does not provide certification for any of its standards. Certification is performed by external accreditation bodies authorized to issue ISO standard certification. Nonetheless, ISO has produced standards related to the certification process, and so it recommends certification applicants to choose certification bodies that follow these standards to ensure that they comply with the necessary quality requirements. There are many different certification organizations: the British Standards Institution (BSI) (UK), the Organisme Français de Certification (OFC) (France), and the ANSI National Accreditation Board (ANAB) (USA) are among the most well-known accreditation bodies worldwide.

2. Certification applicant

ISO 37120 Series targets urban communities, which are defined as cities, municipalities, or local governments defined by a specific administrative district, regardless of their size and location.

3. Certification process

Cities wishing to evaluate their performance with the ISO 37120 Series on Sustainable Cities and Communities need to receive the ISO 37120 standard certification first.

Applicants to this ISO 37120 standard certification can receive five different certification stages:

- Aspiration: a verified score between 30 and 45 core standard indicators.
- Bronze: a verified score between 46 to 59 indicators, including 46 core indicators plus 0 to 13 supporting indicators.
- Silver: a verified score of 60 to 75 indicators, including 46 core indicators plus 14 to 29 supporting indicators.
- Gold: a verified score of 76 to 90 indicators, including 46 core indicators plus 30 to 44 supporting indicators.
- Platinum: a verified score of 91 to 100 indicators, including 46 core indicators plus 45 to 54 supporting indicators.

Unlike other standards, ISO does not request that cities report on all indicators. Instead, depending on their objectives, cities can choose the appropriate set of indicators to examine and report on. Thus, the standard aims to operate as an instrument for local authorities and policy makers to evaluate their performance; they can ultimately decide what aspects to examine.

Certified cities must undergo an annual recertification process. As of July 2021, 92 cities in 28 countries have received ISO 37120 certification.

Once cities have received an ISO 37120 certification, they are then eligible for ISO 37122 and ISO 37123 certifications.

4.1.3 OECD Smart City Measurement Framework

OECD Smart City Measurement Framework assesses the performance of smart cities. This framework seeks to evaluate both the degree and impact of digitalization in cities around the world, as well as the engagement and participation of city actors in developing smart cities.

1. Standard topic
OECD Smart Cities Measurement Framework evaluates and compares cities' policies to introduce digitalization in local services and stakeholders' engagement in developing inclusive, sustainable, and resilient societies.

2. Standards categories.
The framework has three categories, referred to as pillars in the OECD publication:

A. Digitalization, which measures digital innovation at the city level by the use of ICTs;
B. Engagement, which measures the involvement of city stakeholders in building the smart city;
C. Smart city performance, which measures four main elements of urban life: well-being, inclusion, sustainability, and resilience.

Table 12. Categories and Subcategories of the OECD Smart City Measurement Framework

Category	Subcategory
Digitalization	Connectivity
	Mobility
	Jobs and firms
	Housing and built environment
	Health and safety
	Education and skills
	E-government
	Energy, water, and waste
Engagement	Inclusiveness and equity
	Capacity and information
	Efficiency and effectiveness
	Adaptiveness
Smart city performance (Well-being)	Jobs
	Income
	Housing
	Access to services
	Education
	Political participation
	Health
	Environmental quality
	Personal safety
	Community
	Life satisfaction
Smart City performance (Inclusion)	Economic
	Gender and LGBT+
	Migrant and ethnic
	Inter-generational
Smart City performance (Sustainability)	Energy
	Climate
	Biodiversity
	Material footprint
Smart City performance (Resilience)	Health and social
	Institutions

Water-related categories are shown in bold.

3. Standards indicators

The three categories of the OECD Smart City Measurement Framework break down into 32 sub-categories and 93 indicators. These indicators measure input, output, and outcomes. Output indicators are more widely used, which allows evidence of what the city produces in terms of digital services and facilities. These indicators provide information of ICTs equipment in the city, including in the case of water services, the percentage use of water meters. In addition, the framework also measures the expenditure employed in research and development in the city which tells us the financial and capacity building resources that the city allocates for digitalization. Several indicators are also designed to measure outcomes, and in that, we find several instances where life or city satisfaction and feelings of safety are measured elements. There are two indicators on urban water services.

Table 13. Water Indicators in the OECD Smart City Measurement Framework

Category	Subcategory	Indicator
Digitalisation	Energy, water, and waste	Percentage of households equipped with smart water meters
		Percentage drinking water under water quality monitoring by real-time water quality monitoring stations

4. Standard metrics
To allow for comparison, indicators frequently use percentages and fractions as metrics. Such is the case for all the indicators concerning water resources management and services in the digitalization category. For certain indicators, such as life satisfaction and those in the engagement category, the standard employs the Linkert scale, by which the evaluator evaluates the performance of the city by giving it a value between two values (commonly, between 0 and 10, where 0 corresponds to a bad performance and 10 a good performance). In doing so, the Linkert scale transforms qualitative characteristics into quantitative values, which facilitates cross-city comparisons.

4.2. Non-governmental organizations and the private sector

4.2.1 CITYKeys Smart City Index

CITYKeys was a research project undertaken by a consortium of universities and research centers under the direction of Research Professor, Airaksinen Miimu, at the Technical Research Centre in Finland. As part of this project, the CITYKeys researchers developed the Smart City Index, composed of 76 city indicators measuring technological, economic, and social aspects of cities.

1. Standard topic
The CITYKeys project defined indicators to measure “smart cities”, cities that mobilize and use available resources for improving the quality of life for its inhabitants and visitors. These indicators constitute the “Smart City Index” and measure quality of life, resource efficiency, innovation and green economy, and local democracy.

2. Standards categories
The standard has four categories which correspond to the four key areas of smart cities: People, Planet, Prosperity, and Governance. The categories break down into 19 subcategories, as indicated in Table 14. Water is included in the Planet category, in two subcategories (Materials, Water and Land; Ecosystem). The first subcategory examines the uses and the status of urban water, as well as materials and land. The second subcategory looks at the share of green and water spaces in the city.

Table 14. Categories and Subcategories of CITYKeys Smart City Index

Category	Subcategory
People	Health
	Safety
	Access to (other) services
	Education
	Quality of housing and the built environment
Planet	Energy & mitigation
	Materials, water, and land
	Climate resilience
	Pollution and waste
	Ecosystem
Prosperity	Employment
	Equity
	Green economy
	Economic performance
	Innovation
	Attractiveness and competitiveness
Governance	Organization
	Community involvement
	Multi-level governance

Water-related categories are shown in bold.

3. Standards indicators

76 indicators have been established to examine and compare smart cities. 22 indicators are employed in each of the Planet, People, and Prosperity categories, plus 10 indicators serve as measures in the Governance category. They are mostly output indicators, although one input indicator is also included in the multilevel subcategory-expenditure by the local authority for a smart city transition. There are 5 indicators concerning water and they are all output indicators.

Table 15. Water Indicators in CITYKeys Smart City Index

Category	Subcategory	Indicator
Planet	Materials, water, and land	Water consumption
		Grey and rainwater use
		Water Exploitation Index
		Water losses
	Ecosystem	Share of green and water spaces

4. Standard metrics

The quantitative metrics of the indicators facilitate comparison between cases. Percentages and ratios are widely employed in the Prosperity and Planet categories. The standard has also established Linkert scales to measure qualitative variables. The Likert scale evaluates based on a value scale between 0 (not at all) and 5 (excellent). A Likert scale requires some understanding of the city context for an accurate assessment to take place.


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4.2.2 Leed for Cities and Communities

The Leadership in Energy and Environmental Design (LEED) for Cities and Communities is a global standard and certification scheme that measures and certifies cities' sustainability performance and quality of life. The standard has been developed by two American organizations, the U.S. Green Building Council (USGBC) and the Green Business Certification Inc. (GBSI). USGBC has developed the LEED standard, while the GBCI issues the LEED certification to third party applicants.

1. Standard topic

The LEED for Cities and Communities standard seeks to evaluate urban sustainability. It looks at cities, understood as places with a governing body (i.e. cities, towns, counties, and other local government jurisdictions), and communities, which refer to "non-city places", including regions, districts, business improvement districts (BIDs), economic development zones, neighborhoods, campuses, and military installations–places that have responsibilities over services provision but no government jurisdiction.

2. Standard categories

The standard is divided into 9 categories and 40 subcategories considered central elements for a sustainable city. One of the categories concerns water access and quality. This category breaks down into 5 subcategories, as presented in Table 16.

Not all subcategories are the same. Amongst all the subcategories, the LEED for Cities and Communities identifies some elements that are more important for a city than others. For instance, in the Water category, guaranteeing adequate access to safe drinking water is considered a fundamental element for a city. In the energy category, having access to a reliable and resilient source of energy is also considered a requirement for a sustainable city.

Table 16. Categories and Subcategories of LEED for Cities and Community Standard

Category	Subcategory
Integrative process	Integrative planning and leadership
	Green building policy and incentives
Natural systems and ecology	Ecosystem assessment (required)
	Green spaces
	Natural resources conservation and restoration
	Light pollution deduction
	Resilience planning
Transport and land use	Transportation performance
	Compact, mixes use and transit-oriented development
	Access to quality transit
	Alternative fuel vehicles
	Smart mobility and transportation policy
	High-priority site
Water access and quality	**Water access and quality (required)**
	Water performance
	Integrated water management
	Storm water management
	Smart water systems
Energy and greenhouse gas emissions	Power access, reliability, and resilience (required)
	Energy and Greenhouse Gas Emissions Performance
	Energy Efficiency
	Renewable Energy
	Low Carbon Economy
	Grid Harmonization
Material and resources	Solid Waste Management (required)
	Waste Performance
	Special Waste Streams Management
	Responsible Sourcing for Infrastructure
	Material Recovery
	Smart Waste Management Systems
Quality of life	Demographic Assessment (required)
	Quality of Life Performance
	Trend Improvements
	Distributional Equity
	Environmental Justice
	Housing and Transportation Affordability
	Civic and Community Engagement
	Civil and Human Rights
Innovation	Innovation
Regional priority	Regional Priority

Water-related categories are shown in bold.

3. Standard indicators

The LEED for Cities and Communities standard has developed indicators for each subcategory. For the Water Access and Quality category, 8 indicators have been adopted, as indicated in Table 17 below. A combination of quantitative and qualitative indicators is employed to measure outcome, processes, and inputs. Outcome indicators measure cities' results, such as access to water and sanitation and quality of infrastructure. Process and input indicators are also employed, such as the adoption of water balance statement or water audits. They are mostly qualitative and measure the actions and resources in place in a city or community.

Table 17. Subcategories and Indicators of the Water Access and Quality Category–LEED for Cities and Community Standard

Category	Subcategory	Indicator
Water access and quality	Water access and quality	Access to water and sanitation
		Quality of drinking water
		Quality of treated wastewater
		Quality of stormwater infrastructure
	Water performance	Water Performance Score
	Integrated water management	Adoption of a water balance statement
	Storm water management	Number of flooding incidents in past 5 years
	Smart water systems	Existence of water audit

4. Standard metrics

The standard uses quantitative metrics–percentages and rates. In the case of water performance, the necessary information can be generally obtained directly from the urban water providers–access to water, water quality, and infrastructure. The standard has also established performance scores. In the case of water, a Water Performance Score has been defined, which is computed by considering the volume of water used.

Certification Scheme

1. Certification organisation

The Green Business Certification Inc. (GBCI) and the U.S. Green Building Council (USGBC) provide the independent oversight and the certification of the LEED standard.

2. Certification applicant

Cities and communities can apply to the LEED for Cities and Communities certification. Examples of actors able to apply for a LEED certification include:

- A city or county manager representing a jurisdiction
- A private sector planner developing a new city or community
- A local developer working on a district or collection of buildings on an urban site/block within a mature city
- A housing authority or local group measuring the sustainability of a neighborhood

In this sense, the LEED certification is not restricted to public or private organizations or areas of a particular size or population; a wider definition of applicant is provided. In addition, the certification distinguishes between new cities and existing cities. Existing cities can submit to receive a certification resulting from measuring the performance of their present social, economic, and environmental conditions at a citywide scale or at a community level, whereas new cities and communities can apply to obtain a "Plan + Design" certification which estimates their performance in the planning, design, and development stages.

3. Certification process

The process to receive the certification is divided into three stages:

- **Precertification** is an optional stage, whereby the applicant submits an initial document stating the overview, goals, strategies, and roadmap for the sustainability activities by city, with the purpose of having an initial examination of its status before submitting all the certification requirements. The precertification helps the applicant better understand the strength and weaknesses of project circumstances, which might help to put in place remediation measures.
- **Certification** is the main step in the certification process. It consists of the city or community documenting sustainable strategies it has undertaken, according to requirements, and receiving its first certification if it meets the standards.
- **Recertification.** After having received a certification, cities and communities are invited to resubmit performance data in the future to receive an updated score, thus renewing their certification.

In addition, the LEED standard employs an online scoring and benchmarking platform where cities can include their metrics across an array of performance indicators and share the results. The objective of this voluntary measure is to inform others about success stories and promote "healthy competition".

4. Type of certification

The GBCI examines and reviews the submitted data and gives a score to the cities and communities according to the standards established. After successful review, the submissions that meet the minimum requirements receive a minimum score of 40 points and can receive the LEED certification. In addition, cities can also be given one of four levels of certification, which reflects different degrees of achievement. Depending on the value of the indicators, the city or community gets a score. The higher the score, the better the city or community's performance is considered to be. The score that the applicant earns determines the level of LEED certification that cities and communities receive:

- LEED Certified: a verified score of 40-49
- LEED Silver: a verified score of 50-59
- LEED Gold: a verified score of 60-79
- LEED Platinum: a verified score of 80+

By means of recertification, an applicant can improve their score, or equally, lose points if their performance has worsened. The objective of these different scores is to encourage cities and communities to identify ways of improving their scores and performance and for them to understand the reasons why they may have deteriorated. Cities and communities that have received the certification frequently display this achievement in their websites and publications.

4.2.3 Arcadis Sustainable Cities Water Index

This index has been prepared two private organizations: Arcadis, a consultancy firm specialized in natural and built assets, and the Centre for Economics and Business Research (CEBR), an economic consultancy firm. This standard builds on the earlier Arcadis Sustainable Cities Index, which addressed various aspects of urban sustainability, and focuses solely on the water sector. The index has 17 indicators which measure three elements of water resources management in cities: resilience, quality, and efficiency. Within these categories, the indicators create an overall ranking for cities around the world.

1. Standard topic

The Arcadis Sustainable Cities Water Index examines the urban water sustainability. Water sustainability regards three main areas: water resiliency, efficiency, and quality. Cities are ranked according to how sustainably they manage and maintain water, as well as how exposed and vulnerable to natural risks they are.

2. Standard categories

This standard is divided into three categories: water resilience, water efficiency and water quality:

- Water resilience relates to the capacity of adaptation of the city in the face of water challenges, such as too much water (floods) and too little water (droughts).
- Water efficiency deals with how effectively and cost-efficient a city can provide water services.
- Water quality is a category to measure how clean and healthy water supply is in a city.

3. Standard indicators

To measure water resilience, this standard looks at six different indicators: water-related disaster risk, flood risk, water stress, water balance, reserve water, and green space.

To measure water efficiency, the standard looks at the presence of non-revenue water (leakage), water charges, metered water, reused wastewater, service continuity, sanitation, and drinking water.

To measure water quality, the standard looks at sanitation, characteristics of drinking water coverage, extent of water treatment, presence of water-related diseases, protection of threatened species dependent of water resources, and the presence of water pollution.

In total, 19 input indicators enter the water index: 6 in the Resilience category, 7 in the Efficiency category, and 6 in the Quality category. Two of them (drinking water and sanitation) appear in Efficiency and Quality categories, as they define both services.

Not all the indicators are the same; however, they are weighted according to their relative importance to water sustainability and quality of life. Having access to drinking water and to sanitation, two essential elements for public health and life, rank the highest. At the bottom of the table is Reused Wastewater, which helps to put less strain on existing water supplies and can create positive returns on investment. However, it is considered less important to ensure water sustainability and well-being. Information on the rank of each indicator is presented in Table 18.

4. Standard metrics

This standard employs quantitative metrics–percentages, number per capita, average costs, etc. The standard developers have indicated for each indicator where the information can be found which helps to identify adequate, comparable, and reliable sources for the information requested. For instance, it suggests using data made available by WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation when information on drinking water supply and sanitation is necessary. Data by the World Bank and from the municipal service providers can provide the necessary evidence to measure performance on metered water and leakage.

Table 18. The Arcadis Sustainable Cities Water Index Categories, Indicators and Metrics

Category	Indicator	Rank	Metrics
Resilience	Water-related disaster risk	3	Number of different types of water-related natural disasters a city is exposed to, including floods, storms, droughts and mud flows.
	Flood risk	3	Number of floods experienced between 1985–2011
	Water stress	5	Percentage of freshwater withdrawn/total available locally
	Water balance	6	Monthly deficits and surpluses of rainfall
	Reserve water	8	Reservoir capacity within 100km of city, relative to total city water supply
	Green space	14	Percentage of city area covered with green space
Efficiency	Drinking water*	1	Percentage of households with safe and secure drinking water.
	Sanitation**	2	Percentage of households with access to improved sanitation.
	Service continuity	9	Continuity of service, average hours per day over the whole network.
	Leakage	10	The proportion of water lost in transit. Includes unbilled consumption, apparent losses, and physical leakage.
	Metered water	12	Percentage of households whose water consumption is metered.
	Water charges	13	Average cost per cubic meter of water to consumers, relative to average income in city.
	Reused wastewater	16	Wastewater reuse compared to total wastewater produced.
Quality	Drinking water*	1	Percentage of households using an improved drinking-water source.
	Sanitation**	2	Percentage of households with access to improved sanitation.
	Water-related disease	4	Incidence of water/sanitation related disease per capita.
	Raw water pollution	7	Concentration of phosphorus and sediment yields from source
	Treated wastewater	11	Percentage of wastewater treated.
	Threatened freshwater amphibian species	15	Percentage of freshwater amphibian species classified by the International Union for Conservation of Nature as threatened in an area.

Same indicators on *Drinking water and **Sanitation in Efficiency and Quality categories.

4.2.4 KWR City Blueprint Approach

The City Blueprint Approach is an assessment tool to measure Integrated Water Resources Management (IWRM) in cities. It has been developed by KWR Water Research Institute, a research centre based in the Netherlands. The City Blueprint Approach helps cities identify local strategies towards sustainability.

1. Standard topic

City Blueprint Approach is an assessment tool developed to evaluate the sustainability of urban water resources. It has been established as a response to extreme weather events such as floods and drought to help cities to improve their water resources management and water services performance.

2. Standard categories

The City Blueprint Approach examines three complementary categories:

1. The Trends and Pressures Framework (TPF) examines what urban water challenges cities face and it has three subcategories: social pressures, environmental pressures, and financial pressures.
2. City Blueprint Framework (CBF) assesses how effectively cities manage their urban water cycle from water provision to climate change and governance.
3. Governance Capacity Framework (GCF) examines how cities manage their water resources.

3. Standard indicators

In total, the City Blueprint Approach has 63 indicators in the three framework categories. The TPF and CBF categories tend to measure outputs, as they provide a diagnosis of the current circumstances in the city. The GCF category gathers information on inputs, such as resources, capacities, staff, and expertise, that the cities have put in place to bring about a sustainable and integrated management of water resources in cities.

- **Trends and Pressures Framework (TPF)**

  12 indicators measure the social, environmental, and financial trends and pressures faced by the local city. Indicators such as urbanization rate, water scarcity, flood risks, unemployment, etc. provide information on the background and the context of the cities. Each indicator receives a number according to the following scale from 0 to 4 points: 0-0.5 points (no concern), 0.5-1.5 points (little concern), 1.5-2.5 points (medium concern), 2.5-3.5 points (concern), and 3.5-4.0 points (great concern).

- **City Blueprint Framework (CBF)**

  24 indicators constitute the CBF category which examines how successfully cities manage different urban service provision and undertake sustainability plans. They measure aspects such as water quality, solid waste treatment, basic water services, wastewater treatment, infrastructure, and more.
  With the information collected for each indicator, a score is given from 0 (bad performance) to 10 (excellent performance). The values of each indicator are plotted in a spider diagram which reflects the strengths and weaknesses of their performance. Then, following existing indicator scores, cities are classified into five categories (1) cities lacking basic water services, (2) wasteful cities, (3) water efficient cities, (4) resource efficient and adaptive cities, and (5) water wise cities (Koop & Van Leeuwen, 2015).

• Governance Capacity Framework (GCF)

The GCF category includes 27 indicators in three subcategories: Knowing, Wanting, and Enabling. In the subcategory, Knowing, the indicators assess whether the local government has the appropriate understanding of the urban water challenges of a given city. In the subcategory, Wanting, the indicators measure whether the local level has an adequate mindset to confront these challenges as well as responsible actors with a willingness to do it. In subcategory, Enabling, the indicators examine whether the local government has the financial, administrative, and organizational capacities to adopt the measures needed.

Table 19. Categories, Subcategories, Dimensions, and Indicators of KWR City Blueprint Approach

Category	Subcategory	Dimension	Indicator
Trend and Pressures Framework	Social Pressures	-	Urbanization rate
			Burden of disease
			Education rate
			Political instability
	Environmental Pressures		Flooding
			Water scarcity
			Heat Risk
	Financial Pressures		Economic pressure
			Unemployment rate
			Poverty rate
			Inflation rate
City Blueprint Framework	-	-	Water footprint
			Water scarcity
			Water self-sufficiency
			Surface water quality
			Groundwater quality
			Sufficient to drink
			Water system leakages
			Water efficiency
			Drinking water Consumption
			Drinking water quality
			Safe sanitation
			Sewage sludge recycling
			Energy efficiency
			Energy recovery
			Nutrient recovery
			Average age sewer system
			Infrastructure separation
			Climate commitments
			Adaptation Strategies
			Climate-robust buildings
			Biodiversity
			Attractiveness
			Management and action plans
			Public participation

Category	Subcategory	Dimension	Indicator
Governance Capacity framework	Knowing	Awareness	Community of knowledge
			Sense of urgency
			Behavioural internalization
		Useful knowledge	Information availability
			Information transparency
			Knowledge cohesion
		Continuous learning	Smart monitoring
			Evaluation
			Cross-stakeholder learning
	Wanting	Stakeholder engagement process	Stakeholder inclusiveness
			Protection of core values
			Progress and variety of options
		Management ambition	Ambitious and realistic goals
			Discourse embedding
			Management cohesion
		Agents of change	Entrepreneurial agents
			Collaborative agents
			Visionary agents
	Enabling	Multilevel network potential	Room to manoeuvre
			Clear division of responsibilities
			Authority
		Financial viability	Affordability
			Consumer willingness to pay
			Financial continuation
		Implementing capacity	Policy instruments
			Statutory compliance
			Preparedness

4. Standard metrics

The City Blueprint Approach employs quantitative data on urban water performance and urban characteristics. One of its main characteristics, however, is that it uses Likert scales extensively by grading TPF in a scale from 0 to 4 for the TPF category) and from 0 to 10 for the CBF category. By doing this, the evaluation allows for a comparison between categories and between cases.

5. Certification Scheme

The City Blueprint Approach is not a certification, but an assessment method for identifying cities' strong and weak points in its management of water resources. The City Blueprint Approach method has been employed by analysts and scholars interested in comparative urban sustainability to understand and compare the functioning and activities of cities. It is one of the tools made available by Watershare, a network of water research organizations and utilities dedicated to water research with global and local collaboration. The City Blueprint Approach guidelines highlight the need for assessments to be done in collaboration with local stakeholders, as they have access to expert knowledge and will employ the results quickly.

To assess city's sustainability with the City Blueprint Approach, three main steps are followed:

1. Information collection, which consists of the gathering of relevant information via a literature review on the circumstances that the city faces, a questionnaire issued to the city authorities, and quality control of the data check, which is then shared with city authorities.
2. Information processing, which consists in calculating the score of the City BluePrint Framework category on a scale of 0 to 10. The score on the Trends and Pressures Framework is also calculated.
3. Contextualization, which consists of providing an account of the local urban water resources management performance by drawing from the information collected with the City Blueprint Approach, as well as with the existing literature and other cities' assessments and explanations.

More than 125 cities and regions in more than 40 countries have been examined following the City Blueprint Approach since 2011, such as Ahmedabad (India), Amsterdam (Netherlands), Bandung (Indonesia), Cape Town (South Africa), Dar es Salaam (Tanzania), Hamburg (Germany), Ho Chi Minh City (Viet Nam), Istanbul (Turkey), Melbourne (Australia), Quito (Ecuador), Rotterdam (Netherlands), and Seoul (Republic of Korea). City Blueprint Approach offers an online platform providing information to cities for knowledge exchange. By using this platform, cities can learn practical lessons from other cities that have already implemented certain measures and learn from their example.

4.2.5 AWS International Water Stewardship Standard

The International Water Stewardship Standard was developed by the Alliance for Water Stewardship (AWS) to examine how water is protected at a site and catchment level according to environmental, social, and economical criteria. It serves as guidance for the adoption of protective measures. The standard has 98 indicators.

1. Standard topic

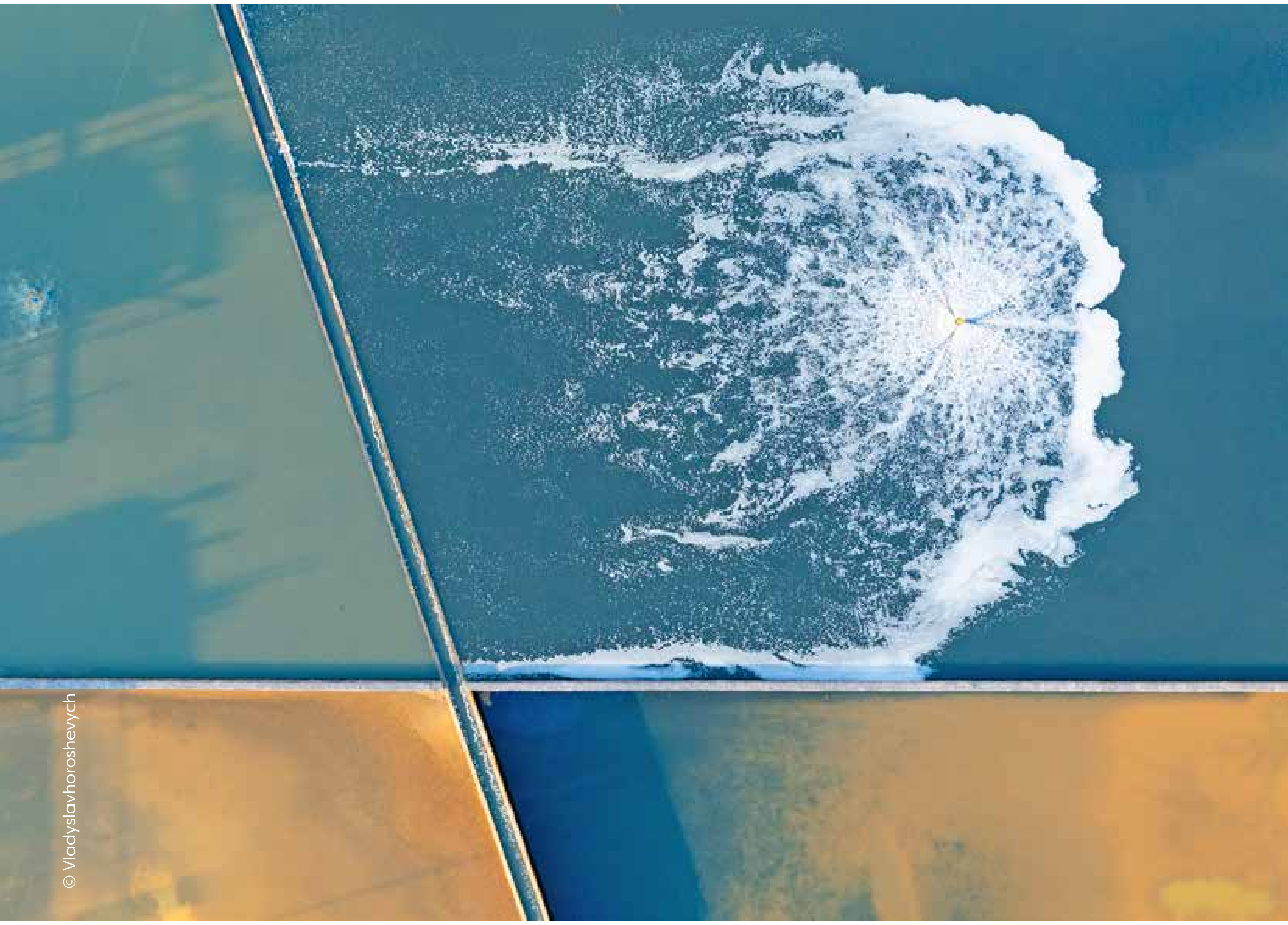
The International Water Stewardship Standard seeks to evaluate water resources sustainability in sites and river catchments.

2. Standards categories

To examine the degree of sustainability of sites and catchments, the standard is divided into five categories of analysis (Gather and understand; Commit and plan; Implement; Evaluate; and Communicate and disclose). Each category corresponds to different steps of the policy-making cycle. Each of the 5 main categories are further divided into subcategories which provide further specification of the areas considered. In total, there are 30 subcategories in the standard. The "Gather and understand" category seeks to provide guidance of the information that policymakers need to collect to ensure that the sustainability standards are met. The "Commit and plan" category is about deciding and planning the measures that are going to be put in place. The "Implement" category is the phase when different measures for protecting water resources of sites and river catchments are established. The "Evaluate" category provides guidance to assess what needs to be made for evaluating the measures implemented to protect water bodies. Finally, the "Communicate and disclose" category establishes the guidance for how best to communicate information to the public about water status in sites and river catchment areas.

Table 20. Categories and Subcategories of AWS International Water Stewardship Standard

Category	Subcategory
Gather and understand	Gather information to define the site's physical scope for water stewardship purposes.
	Understand relevant stakeholders, their water related challenges, and the site's ability to influence beyond its boundaries.
	Gather water-related data for the site, including: water balance, water quality, Important Water-Related Areas, water governance, WASH, water-related costs, revenues, and shared value creation.
	Gather data on the site's indirect water use.
	Gather water-related data for the catchment.
	Understand current and future shared water challenges in the catchment by linking the water challenges identified by stakeholders with the site's water challenges.
	Understand the site's water risks and opportunities.
	Understand best practice towards achieving AWS outcomes.
Commit and plan	Commit to water stewardship by having a senior manager in charge.
	Develop and document a process to achieve and maintain legal and regulatory compliance.
	Create a water stewardship strategy.
	Demonstrate the site's responsiveness and resilience to responding to water risks.
Implement	Implement a plan to participate positively in catchment governance.
	Implement a system to comply with water-related legal and regulatory requirements and respect water rights.
	Implement a plan to achieve site water quality targets.
	Implement a plan to achieve site water balance targets.
	Implement a plan to maintain or improve the site's and/or catchment's Important Water-Related Areas.
	Implement a plan to provide access to safe drinking water, effective sanitation, and protective hygiene (WASH) for all workers at all premises under the site's control.
	Implement a plan to maintain or improve indirect water use within the catchment.
	Implement a plan to engage with and notify the owners of any shared water-related infrastructure of any concerns the site may have.
	Implement actions to achieve best practice towards AWS outcomes.
Evaluate	Evaluate the site's performance, considering its actions and targets from its water stewardship.
	Evaluate the impacts of water-related emergency incidents (including extreme events); if any have occurred, determine the effectiveness of corrective and preventative measures.
	Evaluate stakeholders' consultation feedback regarding the site's water stewardship performance.
	Evaluate and update the site's water stewardship plan.
Communicate and disclose	Disclose water-related internal governance of the site's management.
	Communicate the water stewardship plan with relevant stakeholders.
	Disclose annual site water stewardship summary.
	Disclose efforts to collectively address shared water challenges.
	Communicate transparency in water-related compliance.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3. Standards indicators.
98 indicators have been developed for the International Water Stewardship Standard to measure different aspects of the management of water bodies: 34 indicators in the “Gather and understand” category; 10 in the “Commit and plan” category; 36 in the “Implement” category; 8 in the “Evaluate” category; and 10 in the “Communicate and disclose” category (see Table 21).

All indicators are not the same. Out of the 98 indicators, 68 are core indicators, while 30 are advanced indicators. Core indicators concern primary objectives, more relevant and important for the management of water sites. Advanced indicators, while relevant, are secondary.

The indicators are “process indicators,” establishing the actions needed to achieve the sustainability of sites and catchments. The indicators are not measured quantitatively, but qualitatively. They have a wide field of application, as they are not dependent on requisites on input or outputs. Not all indicators have the same value: there are core criteria, which must be met as a minimum requirement for certification, and also advanced criteria, which can award additional points.

Table 21. Categories and Indicators of AWS International Water Stewardship Standard

Category	Subcategory
Gather and understand	Gather information to define the site's physical scope for water stewardship purposes.
	Understand relevant stakeholders, their water related challenges, and the site's ability to influence beyond its boundaries.
	Gather water-related data for the site, including: water balance, water quality, Important Water-Related Areas, water governance, WASH, water-related costs, revenues, and shared value creation.
	Gather data on the site's indirect water use.
	Gather water-related data for the catchment.
	Understand current and future shared water challenges in the catchment by linking the water challenges identified by stakeholders with the site's water challenges.
	Understand the site's water risks and opportunities.
	Understand best practice towards achieving AWS outcomes.
Commit and plan	Commit to water stewardship by having a senior manager in charge.
	Develop and document a process to achieve and maintain legal and regulatory compliance.
	Create a water stewardship strategy.
	Demonstrate the site's responsiveness and resilience to responding to water risks.
Implement	Implement a plan to participate positively in catchment governance.
	Implement a system to comply with water-related legal and regulatory requirements and respect water rights.
	Implement a plan to achieve site water quality targets.
	Implement a plan to achieve site water balance targets.
	Implement a plan to maintain or improve the site's and/or catchment's Important Water-Related Areas.
	Implement a plan to provide access to safe drinking water, effective sanitation, and protective hygiene (WASH) for all workers at all premises under the site's control.
	Implement a plan to maintain or improve indirect water use within the catchment.
	Implement a plan to engage with and notify the owners of any shared water-related infrastructure of any concerns the site may have.
	Implement actions to achieve best practice towards AWS outcomes.
Evaluate	Evaluate the site's performance, considering its actions and targets from its water stewardship.
	Evaluate the impacts of water-related emergency incidents (including extreme events); if any have occurred, determine the effectiveness of corrective and preventative measures.
	Evaluate stakeholders' consultation feedback regarding the site's water stewardship performance.
	Evaluate and update the site's water stewardship plan.
Communicate and disclose	Disclose water-related internal governance of the site's management.
	Communicate the water stewardship plan with relevant stakeholders.
	Disclose annual site water stewardship summary.
	Disclose efforts to collectively address shared water challenges.
	Communicate transparency in water-related compliance.

4. Standard metrics.
The measurement in this standard is not quantitative, but qualitative. The standard's applicants and auditors must assess the situation, grading it according to their observations.

Certification Scheme

1. Certification organisation
The AWS does not provide a certification to the applicants, but accredits three types of service providers: Consultancies, Conformity Assessment Bodies (CABs), and individuals that have received training to become certification suppliers. AWS publishes organizations that can deliver accreditation. The AWS strongly recommends that implementers of the AWS Standard work with the AWS accredited service providers and professionally credentialed organizations to receive certification.

2. Certification applicant
The certification scheme is applicable globally to all organizations and industrial sectors, independently of their size and operational complexity. This includes including agriculture, and non-profit sectors.

3. Certification process
The AWS has established a five-step procedure for applicants to get certifications:

- **Phase 1: Familiarization:** applicants are asked to find about the AWS Standard and reflect on how their site or catchment area meets the indicators.
- **Phase 2: AWS Standard System Training:** applicants participate in a training session that provides key information on the standard, the indicators, and the certification process.
- **Phase 3: Completion and Submission of Certification Applications:** applicants submit their online request to receive a certification for their sites or catchment area.
- **Phase 4: Implementation:** once the information for the AWS Standard is collected, all actions necessary for the certification are adopted.
- **Phase 5: Audit:** the site is audited and any gaps with meeting the standards are highlighted. Once audited and found to be in compliance with the AWS Standard, the sites are awarded AWS Certification.

4. Type of certification
There are three levels of AWS Standard certification that a site may achieve: Core, gold and platinum. All core criteria must be met as a minimum requirement for certification. Additional points are awarded for performance against the advanced criteria. The points required for each certification level are as follows:
- Core: all core standards, plus 0 to 39 points in advanced indicators.
- Gold: all core standards, plus 40 to 79 points in advanced indicators.
- Platinum: all core standards, plus 80 or more points in advanced indicators.

The greater the number of points achieved the higher the level of water stewardship performance and AWS certification. The maximum value of each advanced indicator is established in the accreditation guidelines.

A site's certificate is valid for three years, subject to successful annual surveillance audits. It is expected that over time, applicants will search to adopt more advanced actions in the spirit of improving their performance.

4.3. Comparison of global standards and certification schemes

Several aspects stand out from the comparison of these eight well-established instruments to analyze and evaluate cities from around the world:

1. Variation in the standard topic
The standards vary in their topic subject. Four of the standards analyzed make water sustainability the key topic of the standard (Arcadis Sustainable Cities Water Index, KWR City Blueprint Approach, and AWS International Water Stewardship Standard). Their objective is to measure the environmental protection of water bodies and citizens' access to water resources.

The other four standards make specific references to "smartness" as a central topic (United 4 Smart Sustainable Cities, ISO 37120 series on sustainable cities and communities, OECD Smart City Measurement Framework, and CITYKeys Smart City Index). They are interested in measuring the presence of digital technologies in the provision of urban services. Smart development is, nonetheless, understood as heavily interconnected to sustainability, and so, these standards also refer to the protection of the environment and social inclusion.

In addition, quality of life–understood as citizens' wellbeing–is also an important concern, and thus smart sustainable development is also put in connection to indicators such as access to health and education, safety, food security, etc., in several cases, such as LEED for Cities and Communities, CITYKeys Smart City Index, OECD Smart City Measurement Framework, ISO 37120 Series, etc.

2. Cities as unit of analysis
The city–taken to be the space inhabited by many people living in proximity, and under one administration–is the preferred unit to examine urban sustainable and smart development in most of the examined standards. One standard (AWS International Water Stewardship Standard) uses the term "site" instead, which refers to areas within a river basin. In addition, two standards can be applied to cities and to "communities", understood as smaller urban units such as neighborhoods or city districts. All standards are designed to examine urban areas with different features, irrespective of their size, economic development, governance arrangements, etc.

3. Governance of urban water resources
Six standards except the Arcadis Sustainable Cities Water Index and the United 4 Smart Sustainable Cities do include some indicators on urban governance. Elements such as the existence of coordination between departments, citizen's participation, or mechanisms for monitoring and evaluation are measured. However, the variation in the indicators on governance is large, so no set of the most crucial elements at the city level has been established.

4. Water has a key role in smart sustainable cities
Water plays a key role in all the standards dealing with smart, urban sustainability. Water is key for socio-economic development and life, and thus all standards seek to grasp the extent to which cities provide for a safe and secure access to this finite resource.

However, several of the examined standards only take a partial view of the different functions of water in cities. The United 4 Smart Sustainable Cities, ISO 37120 Series, OECD Smart City Measurement Framework, CITYKeys Smart City Index, and LEED for Cities and Communities standard have a larger scope of analysis than water and include other sectoral policies and dimensions. Thus, the functions of water as a resource and an urban service are only considered with a reduced number of indicators (see Table 22).

Arcadis Sustainable Cities Water Index, KWR City Blueprint Approach, and AWS International Water Stewardship Standard are much more comprehensive in the analysis of the water sector and can be of great help in the design of a future Smart Water City standard scheme. Yet, some limitations concur:

- Arcadis Sustainable Cities Water Index includes 17 indicators to measure and evaluate the functioning of urban water services provision. Some gaps are still present regarding water quality and wastewater collection. Aspects concerning urban governance are not taken into consideration.
- KWR City Blueprint Approach successfully measures characteristics of the city and also pays dedicated attention to the governance of the water sector. However, the standard is concerned with measuring the existing urban water status and not the functioning of water services provision in the city.
- AWS International Water Stewardship Standard takes the river basin and water sites as units of analysis. Therefore, the focus is not on the functions of water in the city, which have particularities that need to be specifically examined (such as, the operation of water services infrastructures, for instance).

5. Characteristics of the indicators: number, hierarchized, quantitative and output measures
With regards to the characteristics of the indicators of the standards examined, various elements need to be highlighted:

- The range of indicators from 19 of Arcadis Sustainable Cities Water Index to 276 of ISO 37120 Series that the standards propose is large. The other six standards have more than 40 indicators. Decisions on the number of indicators have large implications: the more data that the standard collects, the fuller their diagnosis. However, greater data requirements may also make it difficult to collect information in certain city cases and lead to incomplete data gathering exercises. A trade-off between data comparability and exhaustiveness exists.

- Some standards have established a hierarchy of indicators. This means that the collection of certain information is deemed essential, whereas other indicators may help to complement the data gathering exercise.

- Most standards indicators collect quantitative data, gathered in percentages and rates. Doing so facilitates comparisons across city and country cases. In some cases, such as KWR City Blueprint Approach and the CITYKeys Smart

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City Index, the information requested is of a qualitative nature and requires an evaluation. In these cases, the information is collected with a Linkert scale where the evaluator grades the circumstances and the status of water in the city. The LEED for Cites and Communities standard employs a scoreboard. In these cases, it necessary to establish a set of guidelines to ensure the information collected by different researchers/evaluators is reliable and comparable.

• Most of the standards have preferred indicators that account for city outputs, that is, the measure of sustainability or smartness that the city displays. Indicators on the resources employed to achieve such smart and sustainable results (input indicators) are employed less. Process indicators are heavily employed only in the AWS International Water Stewardship Standard, as it accounts in detail the mechanisms and the measures put in place, irrespective of their results or the resources employed.

6. Certification types

In three out of the eight examined standards, a certification can be granted to accredit that a city authority or local organization meets a standard's requirements. This is the case of the ISO 37120 standard as well as the LEED and AWS standards. The three certifications propose different levels of certification depending on what degree of requirement the standard has met:

- Five levels in the case of the ISO 37120 standard;
- Four levels in the case of the LEED standard; and
- Three levels in the case of the AWS standard.

The different types of certifications are used as evidence for grading the performance of cities.

Table 22. Comparison of the Subject, Structure, and Indicators of Eight Global Standards on Smart and Sustainable Water Urban Management

Standard	Subject	Structure	Water-related indicator
United 4 Smart Sustainable Cities	Smart Sustainable Cities	• 3 dimensions (Economy; Environment; Society and Culture) • 7 sub-dimensions (ICT; Productivity; Infrastructure; Environment; Energy; Education, Health and Culture; Safety, Housing and Social Inclusion) • 28 categories • 91 indicators (quantitative)	11 indicators • 2 in water distribution (supply) 1 measuring smart technology • 1 in water distribution (loss) • 2 in consumption • 1 in drinking water (supply) • 1 in drinking water (quality) • 1 in wastewater (collection) • 1 in wastewater (treatment) • 1 in sanitation • 1 in water source (quantity)
ISO 37120 Series (Sustainable Cities and Communities) *	Smart and sustainable cities and communities	• 19 themes • 104 indicators (ISO 37120 standard); 80 indicators (ISO 37122 standard); 68 indicators (ISO 37123 standard), all quantitative	11 indicators (ISO 37120 standard) • 1 in water distribution (supply) • 1 in water distribution (loss) • 2 in consumption • 1 in drinking water (supply) • 1 in drinking water (quality) • 1 in wastewater (collection) • 2 in wastewater (treatment) • 1 in sanitation • 1 in water source (quantity)
			9 indicators (ISO 37122 standard) • 1 in water distribution (supply), measuring smart technology • 1 in consumption, measuring smart technology • 1 in drinking water (quality), measuring smart technology • 1 in wastewater (collection), measuring smart technology • 1 in wastewater (reuse) • 3 in wastewater (resource recovery) • 1 in water source (quality), measuring smart technology
			2 indicators (ISO 37123 standard) • 1 in drinking water (supply) • 1 in water source (quantity)
OECD Smart City Measurement Framework	Smart cities	• 3 pillars (Digitalization; Engagement; Smart City Performance) • 32 sub-categories • 93 indicators (quantitative)	2 indicators • 1 in consumption, measuring smart technology • 1 in drinking water (quality), measuring smart technology

Standard	Subject	Structure	Water-related indicator
CITYKeys Smart City Index	Smart cities	• 4 categories (People; Planet; Prosperity; Governance) • 19 sub-categories • 76 indicators (quantitative – with Likert scale)	5 indicators • 1 in water distribution (loss) • 1 in consumption • 2 in water source (quantity) • 1 in ecosystem
LEED for Cities and Communities*	Cities and communities' sustainability	• 9 categories (Energy; Water; Waste; Transportation; Quality of Life) • 40 indicators (quantitative and qualitative – scoreboard)	8 indicators • 1 Access to water and sanitation • 1 Quality of drinking water • 1 Quality of treated wastewater • 1 Quality of stormwater • infrastructure • 1 on Water consumption per capita (water performance) • 1 on water balance • 1 on flooding • 1 on Water audit
Arcadis Sustainable Cities Water Index	Sustainable water cities	• 3 categories (Resilience; Efficiency; Quality) • 18 indicators (quantitative)	All • 1 in water distribution (supply) • 1 in water distribution (loss) • 2 in consumption • 1 in drinking water (supply) • 1 in wastewater (treatment) • 1 in wastewater (reuse) • 2 in sanitation • 3 in water source (quantity) • 1 in water source (quality) • 2 in ecosystem • 2 in disaster risk
KWR City Blueprint Approach	Cities' Integrated water resources management	• 3 frameworks (Trends and Pressures; City Blueprint; Governance Capacity) • 64 indicators (quantitative – with Likert scale)	All • 1 in water distribution (loss) • 3 in consumption • 2 in drinking water (supply) • 1 in drinking water (quality) • 2 in wastewater (collection) • 4 in wastewater (resource recovery) • 1 in sanitation • 1 in water source (quantity) • 2 in water source (quality) • 1 in ecosystem • 3 in climate change • 3 in social factor • 12 in trends and pressures • 27 in governance capacity
AWS International Water Stewardship Standard*	Water resources sustainability in sites and river catchments	• 5 categories (Gather and Understand; Commit and Plan; Implement; Evaluate; Communicate and Disclose) • 30 sub-categories • 98 indicators	All • 34 indicators in gather and understand • 10 in commit and plan • 36 in implement • 8 in evaluate • 10 in communicate and disclose

* Certification schemes present

4.4. Key findings for the development of a Smart Water Cities global standard and certification scheme

Above all, from the comparison of eight global standards and certification schemes, a paradox emerges: while water is a key element for urban growth and development, we currently lack an instrument to measure and benchmark Smart Water Cities comprehensively. In particular, the comparison shows the existence of two main gaps:

1. The existing standards focus almost exclusively on conventional urban water management. Thus, while some data is collected on the characteristics of the urban service provision such as drinking water and sanitation, we have scarce measurements of other key functions such as reuse and resource recovery, disaster risks, or ecosystem functions which are central to the sustainability of the water urban system.

2. The existing standards pay only reduced attention to the use of smart water technologies, even when they refer to smart development as a standard topic. Tables 23 to Table 31 divide, for each standard, the indicators that measure conventional technologies from smart technologies. It shows the limited number of water indicators that have examined the presence of smart technologies.

As smart technologies become widespread in the water sector, developing an instrument that allows for the examination and the comparison of the urban water system in a comprehensive manner throughout the urban water cycle is becoming more and more necessary. Such an instrument can be helpful in establishing an initial baseline of key elements that cities need to concentrate and deliver on, which can be helpful for policymakers and water providers in identifying and defining urban water management priorities. In addition, such an instrument can be helpful in examining the evolution of a single city, to track its progress (or lack thereof), and point at future measures that cities can take to continue improving their performance. Finally, such a tool can be also employed to compare and benchmark different cities at a moment in time, to identify with greater clarity what measures operate in a more effective and efficient manner in different contexts, and to learn from these experiences with more comprehensive and precise data.

Table 23. Water-Related Indicators in the Examined Standards: U4SSC

Degree of smartness		Basic	Smart technology
Water distribution	Supply	Basic water supply (Percentage of city households with access to a basic water supply)	Water supply ICT monitoring (Percentage of the water distribution system monitored by ICT (advanced))
	Loss	Water supply loss (Percentage of water loss in the water distribution system)	
Consumption		Water consumption (Total water consumption per capita)	Smart water meters (Percentage implementation of smart water meters)
Drinking water	Supply	Portable water supply (Percentage of households with a safely managed drinking water service)	
	Quality	Drinking water quality (Percentage of households covered by an audited Water Safety Plan)	
Wastewater	Collection	Wastewater collection (Percentage of households served by wastewater collection)	
	Treatment	Wastewater treatment (Percentage of wastewater receiving treatment (Primary, Secondary, Tertiary))	
	Reuse		
	Resource recovery		
Sanitation		Household sanitation (Percentage of the city households with access to basic sanitation facilities)	
Water source	Quantity	Fresh water consumption (Percentage of water consumed from freshwater sources)	
	Quality		
Ecosystem			
Disaster risk			
Climate change			
Social factor			

Table 24. Water-Related Indicators in the Examined Standards: ISO 37120 Standard in ISO 37120 Series

Degree of smartness		Basic	Smart technology
Water distribution	Supply	Average annual hours of water service interruptions per household (supporting)	
	Loss	Percentage of water loss (unaccounted for water) (supporting)	
Consumption		• Total domestic water consumption per capita (litres/day) (core) • Total water consumption per capita (litres/day) (supporting)	
Drinking water	Supply	Percentage of city population with potable water supply service (core)	
	Quality	Compliance rate of drinking water quality (core)	
Wastewater	Collection	Percentage of city population served by wastewater collection (core)	
	Treatment	• Percentage of city's wastewater receiving centralized treatment (core) • Compliance rate of wastewater treatment (supporting)	
	Reuse		
	Resource recovery		
Sanitation		Percentage of population with access to improved sanitation (core)	
Water source	Quantity	Percentage of city population with sustainable access to an improved water source (core)	
	Quality		
Ecosystem			
Disaster risk			
Climate change			
Social factor			

Table 25. Water-Related Indicators in the Examined Standards: ISO 37122 Standard in ISO 37120 Series

Degree of smartness		Basic	Smart technology
Water distribution	Supply		Percentage of the city's water distribution network monitored by a smart water system
	Loss		
Consumption			Percentage of buildings in the city with smart water meters
Drinking water	Supply		
	Quality		Percentage of drinking water tracked by real-time, water quality monitoring station
Wastewater	Collection		Percentage of the wastewater pipeline network monitored by a real-time data-tracking sensor system
	Treatment		
	Reuse	Percentage of treated wastewater being reused	
	Resource recovery	• Percentage of biosolids that are reused (dry matter mass) • Energy derived from wastewater as a percentage of total energy consumption of the city • Percentage of total amount of wastewater in the city that is used to generate energy	
Sanitation			
Water source	Quantity		
	Quality		Number of real-time environmental water quality monitoring stations per 100,000 population
Ecosystem			
Disaster risk			
Climate change			
Social factor			

Table 26. Water-Related Indicators in the Examined Standards: ISO 37123 Standard in ISO 37120 Series

Degree of smartness		Basic	Smart technology
Water distribution	Supply		
	Loss		
Consumption			
Drinking water	Supply	Percentage of city population that can be supplied with drinking water by alternative methods for 72 hours	
	Quality		
Wastewater	Collection		
	Treatment		
	Reuse		
	Resource recovery		
Sanitation			
Water source	Quantity	Number of different sources providing at least 5% of total water supply capacity	
	Quality		
Ecosystem			
Disaster risk			
Climate change			
Social factor			

Table 27. Water-Related Indicators in the Examined Standards: OECD Smart City Measurement Framework

Degree of smartness		Basic	Smart technology
Water distribution	Supply		
	Loss		
Consumption			Percentage of households equipped with smart water meters
Drinking water	Supply		
	Quality		Percentage drinking water under water quality monitoring by real-time water quality monitoring station
Wastewater	Collection		
	Treatment		
	Reuse		
	Resource recovery		
Sanitation			
Water source	Quantity		
	Quality		
Ecosystem			
Disaster risk			
Climate change			
Social factor			

Table 28. Water-Related Indicators in the Examined Standards: CITYKeys Smart City Index

Degree of smartness		Basic	Smart technology
Water distribution	Supply		
	Loss		Water losses
Consumption		Water consumption	
Drinking water	Supply		
	Quality		
Wastewater	Collection		
	Treatment		
	Reuse		
	Resource recovery		
Sanitation			
Water source	Quantity	Grey and rainwater use	Water Exploitation Index
	Quality		
Ecosystem		Share of green and water spaces	
Disaster risk			
Climate change			
Social factor			

Table 29. Water-Related Indicators in the Examined Standards: LEED for Cities and Communities

Degree of smartness		Basic	Smart technology
Water distribution	Supply		
	Loss		
Consumption		Water Performance Score	
Drinking water	Supply		
	Quality	Quality of drinking water	
Wastewater	Collection	Stormwater collection infrastructure	
	Treatment	Quality of treated wastewater	
	Reuse		
	Resource recovery		
Sanitation			
Water source	Quantity		
	Quality		
Ecosystem			
Disaster risk		Flooding incidents	
Climate change			
Social factor		Water Balance and audit	

Table 30. Water-Related Indicators in the Examined Standards: Arcadis Sustainable Cities Water Index

Degree of smartness		Basic	Smart technology
Water distribution	Supply	Service continuity (Continuity of service, average hours per day over the whole network)	
	Loss		
Consumption		Leakage (The proportion of water lost in transit. Includes unbilled consumption, apparent losses, and physical leakage)	
Drinking water	Supply	• Metered water (Percentage of households whose water consumption is metered) • Water charges (Average cost per cubic meter of water to consumers, relative to average income in city)	
	Quality	Drinking water (Percentage of households with safe and secure drinking water)	
Wastewater	Collection		
	Treatment		
	Reuse	Treated wastewater (Percentage of wastewater treated)	
	Resource recovery	Reused wastewater (Wastewater reuse compared to total wastewater produced)	
Sanitation			
Water source	Quantity	• Sanitation (Percentage of households with access to improved sanitation) • Water-related disease (Incidence of water/sanitation related disease per capita)	
	Quality	• Water stress (Percentage of freshwater withdrawn/total available locally) • Water balance (Monthly deficits and surpluses of rainfall) • Reserve water (Reservoir capacity within 100km of city, relative to total city water supply)	
Ecosystem		• Raw water pollution (Concentration of phosphorus and sediment yields from source) • Threatened freshwater amphibian species (Percentage of freshwater amphibian species classified by the International Union for Conservation of Nature as threatened in an area	
Disaster risk		• Water-related disaster risk (Number of different types of water-related natural disasters a city is exposed to, including floods, storms, droughts and mud flows.) • Flood risk (Number of floods experienced between 1985-2011)	
Climate change			
Social factor			

Table 31. Water-Related Indicators in the Examined Standards: KWR City Blueprint Approach

Degree of smartness		Basic	Smart technology
Water distribution	Supply		
	Loss	Water system leakages	
Consumption		• Water footprint • Water self-sufficiency • Water efficiency	
Drinking water	Supply	• Sufficient to drink • Drinking water consumption	
	Quality	Drinking water quality	
Wastewater	Collection	• Average age sewer system • Infrastructure separation	
	Treatment		
	Reuse		
	Resource recovery	• Sewage sludge recycling • Energy efficiency • Energy recovery • Nutrient recovery	
Sanitation		Safe sanitation	
Water source	Quantity	Water scarcity	
	Quality	• Surface water quality • Groundwater quality	
Ecosystem		Biodiversity	
Disaster risk			
Climate change		• Climate commitments • Adaptation strategies • Climate-robust buildings	
Social factor		• Attractiveness • Management and action plans • Public participation	

PART 3

CONCLUSIONS AND NEXT STEPS

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Innovation and technology are powerful tools necessary for bringing progress to society. Many of the comforts that people enjoy today are possible thanks to the products and techniques inconceivable only a few generations ago. Technologies and production techniques have radically changed in the last 200 years. While the degree of industrialization across the world has been very uneven, most countries have experienced large industrial developments at least from the mid-20th century or earlier. The 4IR, currently underway, consists in the fusion of mobile digital communication and information technologies (ICTs), supercomputers and robotics, and has had a massive impact on the economy and society, worldwide. Innumerable daily activities today are made possible by ICTs. Telework and online services have become daily routines for thousands of people during the recent COVID-19 pandemic, showing how necessary our reliance on ICTs for growth and development is.

As cities face large challenges regarding climate change, population growth, rapid urbanization and urban inequality and governance difficulties, **digital technologies and ICTs have given evidence of the contribution that they can make to sustainable development.** More concretely, in the water sector, smart technologies have shown their potential to assist with numerous challenges across geographic locations in both developing and developed regions. As well as a vigorous literature on the topic, the nine case studies of this report show how smart technologies have served to provide solutions to water scarcity, water quality deficits, aging infrastructures, deficient urban planning, and more. ICTs have assisted cities to reach policy objectives and international goals for urban development and societal well-being. They have given evidence of the successes that cities have achieved when implementing smart water solutions, the factors that have facilitated their implementation at the local level, as well as the limitations and the obstacles they face.

However, one of the main difficulties of extracting lessons from existing case studies on the use of smart urban technologies is that many of these initiatives have been concerned with slightly different dimensions of urban smart development. Some of them focus on tangible assets, such as ICT, technology, and hard (physical) infrastructure in services. Others pay attention to smart intangible assets, such as the role of ICTs in social, cultural, and human capital, well-being, knowledge, policy, governance, participation, innovation, economy, inclusion, and equity (Ahvenniemi, et al., 2017; Huovila, et al., 2019). When it comes to examining smart water solutions, we see that they have been applied to different water functions in cities (drinking water, water circulation, and wastewater) making it difficult to have an overall comparative view of how cities manage water resources. Relatedly, cities also differ in the type of indicators they employ to measure their performance; some of them account for the resources employed, whereas others are concerned with the effects of their policies or with the impact of the adopted measures. In this sense, the development of a city is understood and measured in different ways. This variation makes it difficult to compare what cities are doing and to understand what measures are most efficient and can be learned from.

For this reason, **developing a specialized and dedicated standard for Smart Water Cities is necessary.** Given the large role of water for the smart and sustainable development of liveable cities, a standard that pays specific attention to the management of these resources at the local scale is both relevant and necessary. **A standard can define the central common aspects of smart, sustainable development, while also examining and comparing solutions in cities with different agendas, contexts, and needs.** Defining a standard for Smart Water Cities can go beyond self-proclamations of being a smart and sustainable city, and instead evaluate the urban performance and give a diagnosis of the status of water and water ICTs in urban settings. In addition, developing a standard can also assist cities in **setting targets and in monitoring performance over time.** This can aid cities in defining their priorities, give them guidance on the appropriate measures or combinations of measures for improving their performance, as well as contribute to its future policy decisions.

What is the best way to develop a global standard for Smart Water Cities? From the analysis of city case studies and the global standards and certification schemes, various lessons are drawn:

- First, **cities are places with singular economic, social, and environmental dynamics that deserve special consideration.** The examined standards and the case studies presented reflect the increasing attention that cities are receiving from developmental agencies and international organizations. A future Smart Water City standard will contribute to these efforts. The incorporation of sublocal entities (communities or sites) and the supralocal level (river catchment basin) are to be considered.

- Secondly, **Smart Water Cities are sustainable water cities.** A future global standard for Smart Water Cities needs to examine the technological solutions and whether they are environmentally sustainable, economically feasible, and socially equitable. Smart water cities indicators need to measure this threefold front.

- Thirdly, **smart city solutions are tailored to local circumstances.** Future Smart Water Cities standard needs to pay attention to and deliver solutions for the diverse circumstances faced by cities across the world. They need to tailor smart proposals to local conditions. Smart water solutions will be responsive to the diverse features of cities, including the size of the city, its rate of urbanization and growth, the status of its infrastructure, its economic development, etc. Implementing smart solutions does not necessarily have to be associated to expensive devices and equipment, nor do smart solutions need to be accessible only to economies capable of affording large expenses in infrastructures, running costs, and maintenance. A Smart Water Cities standard and certification scheme needs to account for these variations.

- Fourthly, **good governance of urban water resources is necessary for Smart Water Cities.** Defining water performance indicators and measuring and collecting water data needs to accompany an assessment of the allocation of policy roles and responsibilities and the presence (or lack thereof) of sufficient coordination across levels of government and policy sectors. The adoption of smart water solutions depends not only on technological prowess and capabilities in a city, but also on other aspects related to institutional frameworks and policy decisions. In this sense, the existence of an appropriate governance framework is just as important as physical infrastructure. The Smart Water City standard will serve its purpose better if the gathered information feed into the design, implementation, and evaluation of projects and policies.

• Fifthly, **the establishment of a Smart Water City standard and certification scheme is not an end but a means for better, more sustainable, smarter, water resources and water services management.** Hence, the standard needs to be adaptable to the existing circumstances as well as to future situations and upcoming technological developments. A future Smart Water Cities standard and certification scheme is an instrument that needs to be revisable and regularly updated. In doing so, it will ensure that it is adjusted to more ambitious targets when they are feasible, while responding to potential drawbacks and difficulties.

Next steps

With the publication of the present report, Stage 1 of the Smart Water Cities project "Identifying Smart Water Cities" concludes, and Stage 2 "Developing Standards" begins–as of January 2022. **The objective for Stage 2 is to define a standard and certification scheme for Smart Water Cities which will help to examine, measure, and compare urban water performance across time and in different cities around the world.** Such standards will serve to examine Smart Water Cities as defined here–i.e. sustainable cities with contactless and intelligent water management for all.

Following the findings in this first report, the development a Smart Water Cities standard involves a comprehensive examination the different functions of water in cities that looks at **the role of water at different stages of the urban water cycle.** KPIs will be developed to assess water performance at each of these stages and to examine the role of existing and potential ICTs to guarantee and improve the management of water resources at the local level.

In addition to the evaluation of the urban water cycle, the standard will account for the sustainability of the urban water system. A smart city does not only employ ICTs, **but also ensures the sustainable management of urban water resources.** Thus, a future Smart Water Cities standard will develop indicators that measure environmental sustainability, social inclusivity, and economic performance.

In this sense, the framework for a future Smart Water Cities standard, which is to be fully defined in Stage 2 of the Smart Water Cities project, can already be seen to consist of three main pillars:

1. **Technical pillar,** which examines the role of conventional water technologies and ICTs at different stages of the urban water cycle. This pillar will measure the effects of human intervention in water services provision and urban ecosystems, as well measure how water technologies can improve local urban water resources management.
2. **Governance pillar,** which will be concerned with the institutional and regulatory set-up for the management of the urban water system. This

pillar will account for elements such as the distribution responsibilities and coordination, business models for water services provision, participatory mechanisms, monitoring and oversight practices;

3. **Prospective pillar,** which is concerned with the potential development of a sustainable growth city under changing circumstances. This pillar will assess future trends and how they can impact urban water systems. Attention is to be paid to changes in urban features (e.g., demographic/social, industrial/economic, and physical/environmental changes), financial conditions (financial independence, water-related investment) and future investment value (e.g., historical, cultural, geomorphological attractions).

In addition to this three-pillar framework and the KPIs for each pillars evaluating urban water resources management, Stage 2 of the Smart Water Cities project will develop the guidelines and instructions that cities will follow to use the KPIs adequately. An accreditation procedure for a future certification scheme for Smart Water Cities around the world will be detailed.

This new phase of the project will involve the participation of water researchers from different disciplines: hydrogeology, engineering, social sciences, and law, but also professionals with hands-on experience with these topics at the local and regional administration and government, in public and private companies, and in non-governmental organizations. IWRA, K-water, and AWC invite interested professionals and organizations to get in touch if they wish to learn more.

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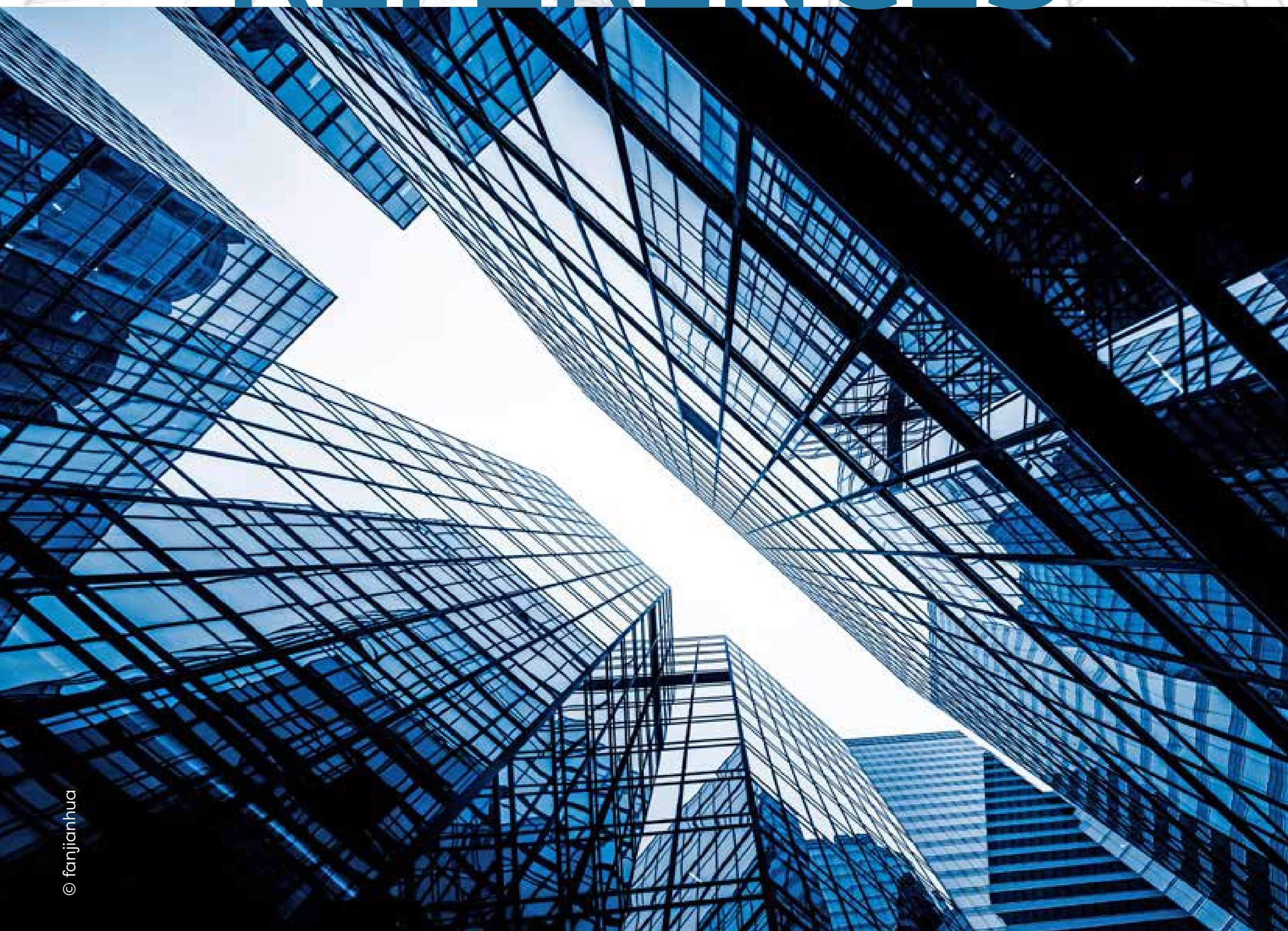

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ANNEX

Smart Water Cities Project Case Studies

1. Algarrobo (Spain)
2. Busan Eco Delta City (Republic of Korea)
3. Ciudad Juarez (Mexico)
4. Heredia (Costa Rica)
5. Hong Kong (China)
6. Mumbai (India)
7. Nakuru (Kenya)
8. New York City (USA)
9. Ningbo (China)

This Annex contains nine case studies, written by 37 authors, on the use of smart water technologies in different regions around the world (see Table 20). Scholars and practitioners submitted their case studies proposals in a joint open call, issued by IWRA, K-water, and AWC, and their proposals were selected for development into the case studies part of this report. Various selection criteria have been employed to ensure a diverse range of case studies for the report. These include geographical location, type of city, scale and water challenge, and regional/national policies and strategies.

All authors received guidelines for facilitating the writing of the cases, which included a discussion of the concept "Smart Water Cities" and questions that their case studies were to reflect on. Authors were provided with a guiding document with a contextual background of the project aiming to ensure that they each presented comparable information and reflected upon key themes and questions. They were also allowed to provide an individualized narrative for their case study, as well as were given full freedom to present their cases in the manner of their preference. So, while each case study follows a similar structure and answers to similar questions, they also reflect the particularities that the individual authors have preferred to highlight. Full texts were reviewed by a committee of experts who provided comments and recommendations to the drafts and requested authors to resubmit second versions addressing reviewer comments and feedback. The final versions were submitted some weeks later, and are, with minor modifications, included as such in this report.

To establish the content of the case studies, the authors have been provided with a structural guide that their chapters should address. They are as follows:

1. Title
2. Short abstract (of no more than 200 words)
3. Introduction to the study
4. Characteristics of the city, including location, size, density, socio-economic development, and speed of urbanization
5. Key water urban challenge(s) addressed and contextual background information for understanding the challenge (for instance, authors may indicate elements of the water status of the city, such as water availability and consumption and water quality, etc.)
6. The innovative smart water technology solution proposed. Authors refer to the scale and timeframe of the smart water project, as well as any KPIs and standards.
7. Technical and non-technical requirements for the implementation of the smart water technologies. If applicable, authors refer to the agencies and companies supporting the implementation of the smart water solution, as well as the government policies that have supported it.
8. Policy implications, recommendations, or next steps, as appropriate to each case study. Authors address issues related to capacity building, governance structures or institutions, awareness raising, education initiatives, etc.
9. Acknowledgments (if applicable)
10. References
11. Appendix of photos, tables, and/or figures with captions.

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Algarrobo (Spain)

RichWater® system for water reclamation in Algarrobo Municipality

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Algarrobo, Spain

Abstract

Municipalities are aware of their role in supporting the sustainable economic development of their cities and regions. Sustainability is key especially in strategic sectors based on the availability of natural resources, like water. The implementation of water reuse schemes is of special relevance in water scarce areas where the lack of irrigation water limits agricultural production, economic growth, jobs creation, and the development of other important economic activities such as tourism. These relevant challenges at urban level have been addressed by RichWater project in La Axarquia (Málaga, Spain) where the economy is strongly based on agriculture and tourism under the current lack of water availability and the pressures suffered by the Municipality to comply with regulatory and economic regional stakeholders.

The project implemented in Algarrobo Municipality (Málaga, Spain), counted with the commitment of the municipalities and other relevant stakeholders (farmers and farmers associations, irrigation communities, the private sector, and academia) who are in need of innovative solutions for accessing alternative water sources and ensuring livelihoods. Smart approaches to reclaimed waters create important market opportunities for subtropical crops production in this area of the Spanish south.

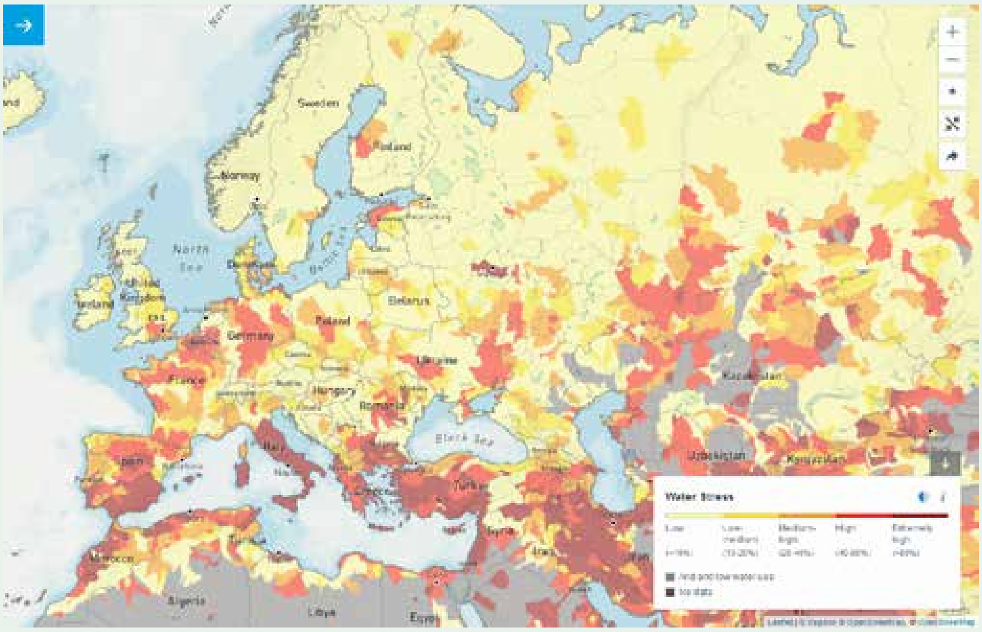
RichWater project has demonstrated an innovative two-in-one solution: wastewater treatment and reclamation technology based on a low-cost and energy-efficient Membrane Bioreactor (RichWater MBR) designed to deliver a nutrient rich effluent for agricultural irrigation and fertilization and to support the transition to a more sustainable economy and a more sustainable agrifood system.

RichWater development has followed an open innovation approach, taking into account first-hand inputs from water operators, farmers and irrigators, public administration, local action groups, as well as inhabitants from the region who has also been involved in project activities. RichWater added value is based on this participatory and bottom-up approach, and it is still evolving in accordance with further requirements. All stakeholders must be part of the development and the solution which increases the potential success in its implementation and market penetration.

Introduction

Considering 'unconventional' water resources is getting more necessary in future hydrological planning. Growing population, the need to produce more food, and current consumption patterns are leading to a steady increase of water and demand for fertilizers (nutrients), putting a growing pressure on water resources which is further exacerbated by the negative effects of climate change. It is expected that around 52% of the world's population will live in water-stressed regions by 2050 (Kölbel et al., 2018).

Figure 1. Water Stress Map



In this context, the use of reclaimed water has a strong potential to provide a reliable alternative source for a number of uses, including agriculture irrigation and fertilization, street cleaning, garden irrigation or other industrial uses– provided that it is treated and/or used safely (WWDR, 2020) and according to appropriate standards and methods (i.e. Guidelines for better water reuse in Europe[1], ISO/TC 282 Water reuse[2]). The use of reclaimed water is also well-recognized as a safe and recommended measure for climate change adaptation and mitigation (WWAP, 2017). It is also essential in meeting the United Nation 2030 Agenda.

Concerns about efficient water use are getting more and more important at the global level and in Europe in the recent past, as reflected in relevant strategic documents, such as the Green Deal, the New Circular Economy Action Plan, and others. Indeed, water reuse is commonly and successfully practiced in several EU Member States, such as Israel, California, Australia, and Singapore. However, this practice is so far deployed below its potential in the EU. According to Water Reuse Europe 2018[3], only 2% of treated wastewater is reused in Europe. More than 40,000 million of m^3 of wastewater are treated in EU every year, but only 964 million of m^3 of this treated wastewater is reused[4]. These figures are expected to grow in the future, with the biggest potential for reuse in Portugal and Spain.

The use of reclaimed water has a huge potential for complementing conventional water resources needed in agriculture production–the backbone for stable food supply in Europe. Agriculture accounts for 40-60% of total water consumption in Europe; most of it is used for irrigation. In southern Member States, agricultural water abstraction accounts for approximately 80% of total water abstraction[5].

1. ec.europa.eu/jrc/en/news/guidelines-better-water-reuse-europe
2. www.iso.org/committee/4856734.html
3. www.water-reuse-europe.org/about-us/wre-activities/water-reuse-europe-review-2018/#page-content
4. EC Infographics: Water is too precious to waste. Available at: ec.europa.eu/environment/water/pdf/water_reuse_factsheet_en.pdf (consulted on 07/07/2021)
5. EEA 2021, Water resources across Europe — confronting water stress: an updated assessment

The implementation of water reuse projects such as RichWater in the Municipality of Algarrobo is of special relevance in water scarce areas where lack of irrigation water is limiting agricultural production and economic growth. Moreover, water scarcity is likely to limit the creation of jobs, since about three out of four jobs in the global workforce are dependent on water (WWAP, 2016).

RichWater project has demonstrated an innovative wastewater treatment and reclamation technology based on a Membrane Bioreactor (RichWater MBR) which has been designed to reuse the effluent in agricultural irrigation and fertilization. This reuse works to reduce pressure in water sources from European regions that are suffering from droughts and water scarcity. In addition, it supports the transition to a more sustainable economy, as the use of reclaimed water for agriculture fertigation, contributing not only to water circularity, but also to closing the nutrient cycle through the valorisation of nutrients embedded in the urban wastewater.

In order to overcome current barriers for the implementation of RichWater MBR, the technology has been verified by the European Commission Environmental Technology Verification (ETV)[6], a tool that helps innovative technologies reach the market. ETV is a service provided by the European Commission through which innovative technologies are verified by qualified third parties, called "Verification Bodies", that use test results to assess claims about the performance and produce a "Statement of Verification". This third-party validation is based on the internationally recognised ISO standard 14034.

The results of the verification process show the performance efficiency of RichWater MBR[7] in treating and reclaiming urban wastewater and delivering high quality nutrient-rich effluent for its reuse in agriculture fulfilling the legal framework. The quality standards applicable for the project are included in the Spanish Royal Decree 1620/2007, which regulates the use of reclaimed water for different purposes in Spain, including agriculture irrigation.

The ETV allows stakeholders such as farmers and public administration to access verified data which prove the RichWater MBR claims included in the Statement of Verification. RichWater MBR is one of the 16 verified technologies in the field of Water Treatment and Monitoring within the ETV programme.

Characteristics of the city

The case study is located in Algarrobo Costa, located in the Algarrobo Municipality, in the province of Malaga, Andalusia, in southern Spain. The municipality belongs to the coastal area of La Axarquía and is 34 kilometers from the city of Málaga. It is bordered on the north by the municipality of Arenas and Sayalonga, by Vélez-Málaga on the east and west, and to the south, the Mediterranean Sea.

6. (2021, October 26). EU Environmental Technology Verification (ETV). Eco-innovation Action Plan - European Commission. Retrieved October 30, 2021, from ec.europa.eu/environment/ecoap/etv.
7. (2021, January 12). RichWater series 2018. Eco-innovation Action Plan - European Commission. Retrieved October 30, 2021, from ec.europa.eu/environment/ecoap/etv/richwater-series-2018_en.

Figure 2. Location of La Axarquia
Source: De Tyk, based File: Andalucía-loc.svg by user: Miguillen - Trabajo propio, CC BY 3.0, commons.wikimedia.org

The municipality has a population of 6,444 residents, of which there are 3,238 men and 3,206 women. Its surface area is 9.73 km^2 and has a density of 662,3 inhabitants/km^2. [8] Main economic activities of the municipality of Algarrobo are agriculture, fishing, and tourism.

La Axarquía, which is composed by 31 municipalities, is known for being the **only area in Europe that produces** tropical fruits. Spain is the only European country with a significant commercial production of avocado and mango, 10,000 hectares and 5,000 hectares, respectively[9]. In Malaga, there are 7,000 hectares of avocado, producing 61,000 tons (2018/2019)[10] and more than 4,000 of mangoes producing 36,000 tons (2018)[11]. Market demand is increasing fast, especially for avocado, due to its global recognition as a "super food" with health benefits. The growth in demand and prices are setting up avocado as one of the top crops to be traded.

Thus, production is a local and regional economic pilar. Municipalities are committed to implementing smart approaches for supporting farmers to take advantage of this important market opportunity. There is a strong interest in the region to have access to scientific results on the cultivation of avocados and mangos with reclaimed water.

This case study is on the use of reclaimed water based on municipal wastewater, to irrigate and fertilize avocado and mangoes trees, in addition to tomatoes plants, as a non-conventional water source to cover crops water demand. Based on the figures given by the head of the Association of Municipalities, if all wastewater available in the region is reclaimed, this would cover 25% of water demand for current crops production.

The positive impacts are at the environmental level–by decreasing pressure on water bodies and eutrophication–and at the socio-economic level–by promoting local economies and job creation and implementing circular economy models allowing closing water and nutrients loops.

8. www.ayuntamiento-espana.es/ayuntamiento-algarrobo.html
9. www.freshplaza.com/article/2148459/spain-avocados-and-mangoes-the-most-profitable-crops/
10. www.projargroup.com/perspectivas-de-crecimiento-del-cultivo-del-aguacate-en-espana/
11. www.freshplaza.com/article/9258184/growing-loyalty-to-spanish-mangoes-in-europe/

Key urban challenges addressed

Water scarcity is a limiting factor for the production of higher value crops, such as subtropical crops (e.g., avocados, mangoes, custard apples, etc.), which is an essential activity for economic development and job creation in La Axarquía. In 2016, the subtropical fruit sector had a turnover of 149 million euros in the province of Malaga, the vast majority produced in the La Axarquía region[12]. In addition, more than 25% of the workers affiliated to Social Security in the region belonged to the agricultural sector, which confirms the importance of agriculture in the economic structure of the region[13]. The lack of water also induces conflicts with other sectors (i.e. tourism), as the Axarquía is a destination with a large holiday influx.

The RichWater project originated from the need to guarantee water access for irrigators of subtropical crops in the region of La Axarquía. These represent a large percentage of the total irrigated agricultural area (about 40%)[14]. Algarrobo Municipality as well as the Association of Municipalities of La Axarquia were very concerned about both, their role in supporting this relevant economic activity of the region and the role of water. In La Axarquia, reclaimed water is an alternative resource of high strategic value in the short-medium term as they are suffering from water shortages that are more and more frequent. Therefore, the local administrations are looking for innovative and competitive solutions for water reclamation and implementation projects. In addition, the Provincial Council of Málaga is asking the municipalities to develop Climate Change Plans and implement integrative solutions for the management of sustainable water.

When the project was approved in 2016, BIOAZUL, project coordinator, together with the partner IHSM La Mayora, started looking for a pilot site location and proposed it to Algarrobo Municipality. The RichWater approach was the solution they were looking for and it provided us with the demo site (wastewater treatment plant and an area owned by the city hall to perform the agronomic trials), as well as provided the contact to all relevant local actors. These contacts crystalised in a formal agreement with the municipality of Algarrobo, the association of municipalities of La Axarquia, and the wastewater treatment operation company, AXARAGUA, which was signed in October 2016. Thus, government, academia, industry, and citizens collaborate together to facilitate the adoption of reuse solutions that cope with the lack of water in the region. Furthermore, as a result of the networking activities carried out within the frame of RichWater, a working group has been set up with key players in the region of La Axarquia, showing their interest and support in the project and its continuity. These agents are the association of Municipalities of La Axarquía, the city council of Algarrobo, the Community of Irrigators of Algarrobo, AXARAGUA, as operator of the wastewater treatment stations of Axarquía, and the Spanish Association of Tropical Crops. The four components of the quadruple helix ensure the real commitment of all actors involved in decision making and the value chain. The objective is to extend the working group and to find external funding to continue with RichWater project activities. The current working group has created an operational group within the EIP-Agri called "AXARQUIA Sostenible" which has already obtained funds from the

12. cadenaser.com/emisora/2017/03/17/ser_malaga/1489744734_242335.html.
13. cederaxarquia.org/axarquia/estrategia-de-desarrollo-local-2014-2020/
14. cederaxarquia.org/axarquia/estrategia-de-desarrollo-local-2014-2020/

regional government to carry out the submission of an implementation project proposal, which was submitted In October 2020 (resolution is pending).

The main source of conventional water for irrigation in the region is the dammed waters from La Viñuela reservoir. In previous years, the amount of water has decreased to less than 30% throughout the year, putting agricultural production at risk. For example, by 29 June 2021, the volume was 50 hm^3, 30.30% of its capacity, 7.88% less than the same week in 2020 (63 50 hm^3) and 31.58% less the same week 10 years ago (102 hm^3).[15]

Andalusia, due to its location in the Mediterranean basin, is a territory for which climate change may risk a reduction in precipitation between 15 and 20% by the year 2050.[16]

Irrigated agriculture is the main water use in Andalusia, with more than 1,000,000 ha of surface. Climate change scenarios for 2050 show an increase in the annual demand for irrigation water of around 20%, an extension of the duration of irrigation campaigns, as well as an increase in peak demand above 10% during summer. If measures aimed at making efficient use of water are not implemented, the water availability scenarios will be deficient. In the case of the province of Malaga, the average annual temperature increase is estimated at 3.6°C in the worst-case scenario, which gives us an idea of the level of water stress these highly dependent crops will be subjected to.

The lack of water due to climate change and population, in terms of both quantity and quality, is therefore a limiting factor for the production of these high value-added crops and the development of other important economic activities, such as tourism, could enter into conflict and discourage the economic development of the municipality and the region. These are the challenges to be addressed at an urban level by the municipalities and to which resolution contributes the RichWater project.

Innovative Smart Water technology solution proposed

Richwater system, with 150m^3 treatment capacity/day of urban wastewater, has been piloted in the operating municipal wastewater treatment plant (WWTP) located in the municipality of Algarrobo within Malaga province (Spain) (36°45'12.1"N 4°02'55.7"W). The urban wastewater plant is managed by AXARAGUA[17] a private-public partnership created by the Association of Municipalities of La Axarquía and treats wastewater from the population of ca. 6,500 inhabitants.

15. www.redhidrosurmedioambiente.es/saih/resumen/embalses.
16. www.juntadeandalucia.es/medioambiente/portal_web/web/temas_ambientales/clima/actuaciones_cambio_climatico/adaptacion/escenarios/elaboracion_escenarios/clima.pdf
17. (2021, October 26). Las reservas de agua de la Axarquía. Axaragua. Retrieved October 30, 2021, from www.axaragua.com.

Figure 3. Algarrobo WWTP and RichWater MBR location
Google maps link: https://goo.gl/JUnQdb.

The RichWater system is composed of four modules: i) wastewater treatment module consisting of a Membrane Bioreactor (MBR); ii) mixing unit; iii) fertigation module; and iv) control and monitoring unit.

The core part of the RichWater system is the Membrane Bioreactor (MBR). It is a compact system for decentralized urban wastewater treatment based on membrane technology. The RichWater MBR system is a logical integration of technologies arranged in a process that leads to obtaining an effluent with the required quality. The processes that make up the complete system are listed below:

- Pre-treatment: Rotary sieve with internal feed with perforated mesh of 2 mm pitch. As the system is in the municipal WWTP facilities, we avoid incorporating grit removal and degreasing processes to capture the water after this process already installed in the main plant.
- Secondary treatment or biological treatment: Composed of two stages:
  - Biological reactor: aeration basin where the bulk of the biological degradation of the contaminants in the wastewater takes place.
  - Membrane tank: where the ultrafiltration membrane module is submerged. This MBR system is configured with the membrane tank separated from the biological reactor for a matter of practicality in maintenance work (chemical cleaning). The concentrated liquor in the filtration process is recirculated to the biological reactor.
  - Tertiary treatment: part of this treatment is given by the separation action exerted by the membranes as a physical barrier against particles larger than the pore of the membrane. In addition, the tertiary treatment is completed with an ultraviolet disinfection system.

Figure 4. RichWater MBR system
Source: BIOAZUL

All processes are controlled by the centralized control system, which also generates data and statistics that allow for optimizing both the treatment process and the maintenance work.

Sludge treatment was not included in this process due to a matter of process optimization, since the municipal WWTP has a sludge treatment system and allowed us to divert the purged sludge in the RichWater MBR system to its dehydration plant.

The design produces high quality effluent that meets the requirements for reclaimed water used for irrigation of crops for human consumption while maintaining high content level of nutrients. It allows to achieve an optimal and simultaneous irrigation and fertilization effect.

RichWater MBR has been verified by an external certified entity, IETU (Poland), under the EC Environmental Technology Verification Programme. The verification sampling campaign took place from the 24th of September 2018 to the 11th of December 2018. A total of 16 samples of the influent entering to RichWater MBR and 16 samples of the RichWater MBR effluent were taken. The total duration of each composite sampling was 24h. Grab samples of influent and effluent for microbiological analyses were collected on Tuesdays and Thursdays. These samples were taken within 2 hours after the autosampler completed the 24-hour sampling. Grab samples of the mixed liquor for MLSS, MLVS analysis were taken from the aeration and membrane tanks on the same days as the samples for microbiological analyses i.e. every Tuesday and Thursday, also within 2 hours after the autosampler completed the 24-hour sampling.

For the RichWater MBR ETV verification, performance parameters and the given limits were assessed, as well as operational parameters as shown in Table 1 and Table 2. The quality of the reclaimed wastewater (effluent) and operational parameters in relation to the performance claims for verification and legal requirements (if applicable) are presented below. The declared values were given at the beginning of the verification and the results obtained during the tests performed for assessing the RichWater MBR.

For some quality parameters the average values are better that the ones declared: Nitrates: 92,31 mg/L; Phosphorus <8 g/m^3, Turbidity 0.69 NTU, BOD5 <15 g O2/m^3, COD was 23,67 g O2/m^3 and Suspended solids < 8 g/m^3. Regarding Process parameters, verification show good performance for wastewater flow, HRT and MLSS concentration in the biological reactor and OLR.

Table 1. RichWater MBR performance indicators

Performance parameters Declared Values	ETV results
Nitrates ≥ 50 mg/l	The average value was 92,31 mg/l, above the declared level. Effluent quality better than declared.
Phosphorus ≥ 1.5 mg P/l	The average value was 4.34 mg P/l, above the declared level. Effluent quality better than declared.
Potassium ≥ 15 mg/l	The average value was 14,43 mg/l Slightly below the declared level.
BOD5 ≤ 25 mg O2/l	The average value was <15 mg O2/l Effluent quality better than declared.
COD ≤ 125 mg O2/l	The average value was 23,67 mg O2/l Effluent quality better than declared.
Suspended solids ≤ 20 mg/l	Concentration below detection limit for all effluent samples (<8 mg/l) Effluent quality better than declared.
Turbidity ≤ 10 NTU	The average value was 0.69 NTU Effluent quality better than declared.

Performance parameters Declared Values	ETV results
Escherichia Coli max 50 CFU/100 mL	In 94% of effluent samples, the concentration was below 50 CFU/100 mL. Only on 09.10.2018 Escherichia Coli content was 90 CFU/100 mL, but it was below the maximum admitted values of this parameter defined for TWW use on tree crops at RD1620/2007 (100 CFU/100 mL).
Legionella spp. max 1000 CFU/L	94% of effluent samples did not contain Legionella. Only on 16.10.2018 Legionella content was 1200 CFU/L. The maximum admitted value of this parameter is 1000 CFU/L for at least 90% samples (RD1620/2007). The sample that exceeds the maximum admitted value did not exceed the maximum deviation limit of 1 logarithmic unit.
Nematodes max 1 egg/10 L	100% of effluent samples did not contain Nematodes.

Table 2. RichWater MBR operational indicators

Operational parameters Declared Values	ETV results
Wastewater flow in the range of 0-10 m^3/h	The wastewater flow in the range of 0.41-4.85 m^3/h,
HRT in the biological reactor in the range of 30-10 h	HRT in the biological reactor in the range of 9.86- 115.90 h
MLSS concentration in the biological reactor $\leq$ 6 kg/m^3	The average concentration of MLSS in the biological reactor 3.476 kg/m^3
OLR < 0.5 kgBOD5/kg ·d	The average value of the parameter 0.08 kgBOD5/kg ·d
DO concentration in the biological reactor in the range of 1.5-2.0 mg/l	DO concentration in the range of 0.05- 2.4 mg/l (DO concentration different than declared)

RichWater MBR allows the production of high-quality reclaimed water rich in the most important plants macronutrients, Nitrogen, Phosphorus and Potassium, as shown in Table 3. Therefore, the reclaimed water has a double effect: irrigation and fertilization. The use of this nutrient rich reclaimed water allows the total or partial replacement of chemical fertilizers from non-renewable resources.

Table 3. Summary of RichWater MBR removal performance

	BOD5 (mg O2/l)	COD (mg O2/l)	TS (mg/l)	TN (mg N/l)	Nitrates (mg N/l)	TP (mg/l)	TK (mg/l)	Turbidity (NTU)
Influent								
Min	93,00	239,00	106,00	25,00	<5	3,30	8,80	2,60
Max	232,00	646,00	397,00	67,00	<5	12,00	25,00	349,00
Average	163,25	408,31	210,06	38,81	<5	5,97	14,81	120,48
Efluent								
Min	<15	15,00	< 8	16,00	5,20	0,16	8,10	0,16
Max	<15	32,00	< 8	45,00	40,68	12,00	24,00	2,30
Average	<15	23,67	< 8	26,00	20,85	4,34	14,43	0,69
Removal %	90,81%	94,20%	96,19%	33,01%	-316,97%	27,31%	2,62%	99,43%

Technical and non-technical requirements for the implementation of the smart water technologies.

In addition to RichWater system technical performace, it is necessary to have a common vision, as well as support and engagement of all value chain stakeholders in the territory and beyond and the legal framework that allows successful and wide implementation. In addition, we have count with the market demand as a driver to push the smart technology.

Stakeholders representing the cuadruple helix have fully committed with the Richwater approach as they understand the use of reclaimed water as an adaptation and mitigation measure for climate change effects that will lead to less availability of water in the region.

Several agencies support Richwater project[18]: The European Commission, Andalusian Regional Government, and EIP Agri and BRIGAID project. The work started with the Horizon 2020 Fast Track to Innovation project formed by 6 international partners and co-funded by the European Commission. The project received 1.67M€ funding from the EC for implementing the project activities in the 33 months of the project's duration (February 2016–October 2018). Partners from three countries (Austria, Germany, and Spain) collaborated to facilitate the adoption of reuse solutions that cope with the lack of water in the region and contributes to boost the agricultural sector: Technology providers: BIOAZUL (MBR module), PESSL, and SMS (sensors), and ISITEC (control module); as well as Academia: CSIC-IHSM (fertigation module) and TTZ (mixing unit).

In addition, 20,325 € funding were mobilized from BRIGAD project[19]. Under BRIGAID, in a six-month period, BIOAZUL developed a nutrient balance calculation tool that calculates the amount of fertilizer needed for irrigation when using reclaimed water. This solution optimizes the use of fertilizers, taking into account the existing nutrients contained in the reclaimed water and therefore, reduce costs for farmers while avoiding an excess of fertilizers that may end up in the eutrophication of other water bodies (e.g. aquifers).

Furthermore, as the project was strategic for municipalities of the region, an Operational Group was created with several territorial stakeholders: the municipality of Algarrobo, the association of municipalities of La Axarquia, AXARAGUA as operator of the wastewater treatment stations of Axarquía; Algarrobo Irrigators Community, the Spanish Association of Tropical Crops and CSIC-IHSM. The group applied for 5,000€ EIP-Agri funding to consolidate the working group, to enlarge the group with new key members, to carry out awareness and dissemination activities, and to enable the innovation project to continue with the activties performed under RichWater.

An extended Operational Group applied in October 2020 for EIP Agri funding to implement the innovation project for 254,993.22€ funding. The extended

18. BIOAZUL. (n.d.). Innovative Wastewater Treatment Technology. Richwater. Retrieved October 30, 2021, from richwater.eu/.
19. BRIGAID is not over yet! BRIGAID EU project is getting to the end, BRIGAID in a nutshel!We are proud of our achievements. ?//brigaid.eu#brigaid_eu #EASME #H2020 #ClimateInnovationWindow Reply on Twitter 1303960430092718083Retweet on Twitter 13039604300927180832Like on Twitter 13039604300927180832Twitter 13039604300927180, & We just published our latest news on BRIGAID. (n.d.). Bridging the gap for Innovations in Disaster Resilience. Brigaid. Retrieved October 30, 2021, from www.brigaid.eu.

group includes producers Associations, such as TROPS and ASAJA, technology providers such as SERAGRO, and the region Local Action Group, CEDER.

The access to further funding will allow activities to continue, further evaluating the revenues for the municipality by "selling" the water to irrigators, decreasing the amount of water and chemical fertilizers consumed, and increasing production capacity.

RichWater is perfectly aligned with the national and European legal framework: Spanish Royal Decree 16020/2007 on water reuse, Water Framework Directive 2000/60/EC, Circular Economy package, Green Deal, Nitrates Directive 91/676/EEC, Urban Waste Water Directive 91/271/EEC, and the recently published Regulation 2020/741 on minimum requirements for water reuse. Moreover, the use of reclaimed water contributes to the achievement of the SDGs, specially to the SDG2 (Zero Hunger), SDG 5 (Gender Equality), SGD 6 (Clean Water and Sanitation), SDG 9 (Industry, Innovation, and Infrastructure), SGD12 (Responsible Consumption and Production), and SGD13 (Climate Action) among others.

RichWater uptaking also supports the implementation of several regional policies and strategies. These include the Andalusian Water Pact, which foresees the implementation of water resue projects, the Circular Bioeconomy Strategy with identified the potential of water and nutrient circularity by the waterwater reclamation, and the Andalusian Climate Action Plan which seeks to transit to a decarbonised economy.

Last but not least, the RichWater project has been recognized at both the national and international level.

In July 2019, RichWater was selected as a Water Oriented living lab by Water Europe and ENOLL as one of the 105 research settings that met assessment criteria (see page 41)[20].

In October 2020, the project received the "Malaga Viva" award from the Malaga Provincial Council for the commitment to using reclaimed water in agriculture as a measure in the fight against climate change.

In June 2021, RichWater was the winner of the Water Europe Innovation Awards 2021 in the modality Water Technology & Infrastructure for its highly promising capability of saving fresh water and fertilizers in agriculture.

Policy implications, recommendations, or next steps

Reclaimed water use is a safe and reliable alternative for agriculture that has certain advantages over other conventional sources. It is a decentralized resource in the territory, has continuous availability, does not depend on climatic events, and provides nutrients that can be directly assimilated by plants.
RichWater acts as a driver in the modernization of agricultural technology and generates quality employment in the design, manufacturing, and

20. Water europe launches new publication 'atlas of the European Water Oriented Living Labs'. Water Europe. (n.d.). Retrieved October 30, 2021, from watereurope.eu/water-europe-launches-new-publication-atlas-of-the-european-water-oriented-living-labs/.

commissioning stages, as well as in the maintenance and operation. Moreover, the availability of reclaimed water for agriculture plays a fundamental role in the so-called “rural renaissance,” allowing the conservation of the rural environment and its ecosystem services and contributing to avoid rural depopulation. It promotes the labor integration of women, which makes up 29% of the workforce in Europe, as one of the main vectors for rural innovation and entrepreneurship.

Reclaimed water use contributes to farmer water sovereignty since its combination with more conventional water sources avoids supply cuts and the consequential losses to food production. It implies a reduction in demand and water pressure on sources for drinking water which may be used for other priority uses, such as tourism or industry.

Lastly, RichWater allows nutrient recovery, reducing the risk of environmental problems (e.g. eutrophication) due to their excess in water bodies. These nutrients are directly assimilated by plants, which leads to savings in chemical fertilizers and consequent economic savings for farmers and irrigation communities. This means a lower carbon footprint since CO_2 emissions are avoided by the production, packaging, and transportation of fertilizers.

At this stage, the ETV verification has recognized the potential of RichWater to provide an effluent to be used in irrigation which is safe and which optimizes the amount of nutrients for the plants. ETV verification helps innovators with the technology commercialization by providing confidence to potential clients and guarantees that performance data is credible and accurate. These guarantees are particularly relevant in the context of water reuse since negative public perception has been recognized as one of the main barriers for the use of reclaimed water in agriculture.

The next steps of the project are mainly focused on continuing with innovation activities, together with all territorial stakeholders, to get sound results on the use of reclaimed water in the productivity of plants, quality of fruits and biodiversity of the soil. This is what the municipalities are requesting for the further implementation of water reuse projects in the municipalities of the La Axarquia Region. Hopefully, these activities will be implemented with EIP Agri funding for the Operational Group innovation project.

The recent approval of EU Regulation 2020/741 implies the application of more stringent standards in terms of water quality for reuse in agriculture. This scenario implies further investments in wastewater treatment and reclamation to comply with the new legal requirements. In this sense, membrane technologies as RichWater have proven to be a reliable solution to extend water reuse.

Finally, RichWater has proven its potential to fertigate and provide nutrients to the plant. This is one of the main benefits of using reclaimed water for irrigation. Nutrients contained in the reclaimed water are directly assimilated by the plants and can therefore partially replace conventional chemical fertilizers. This then accounts for economic savings to farmers and a reduction on the dependency of chemical fertilizers. Cost-benefit analyses are to be performed to demonstrate economic savings as well as the ecological footprint assessment and environmental benefits of using reclaimed water.

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Busan Eco Delta City (Republic of Korea)

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Busan City (Republic of Korea)

Introduction

Busan is the 2nd most populated city in Korea with 3.3 million residents. Between Nakdong River and West Nakdong River, Busan Eco Delta City (BEDC) is being developed by Busan Metropolitan Government, K-water, and Busan Metropolitan Corporation since 2012 under the MOLIT's waterfront development project in accordance with the Special Act on the Utilization of Waterfronts (Figure 1).

Figure 1. Map of Busan and Location of Busan Eco Delta City
Source: Modified from K-water (2018)[1]

The main purpose of the BEDC development is to vitalize economic growth in Busan metropolitan area which has a population of nearly eight million and facilitate cultural and leisure activities along the rivers. Putting in the capital of 660 trillion KRW (about 660 billion USD), new urban districts of housing, commerce, R&D, and logistics will be constructed in the 11.8 km^2 area of BEDC until 2023. Also, this new town will be home for 76,000 people with 30,000 new housing.

For the following sections, Busan Eco Delta Smart City and its Key Performance Indicators (KPIs) are represented.

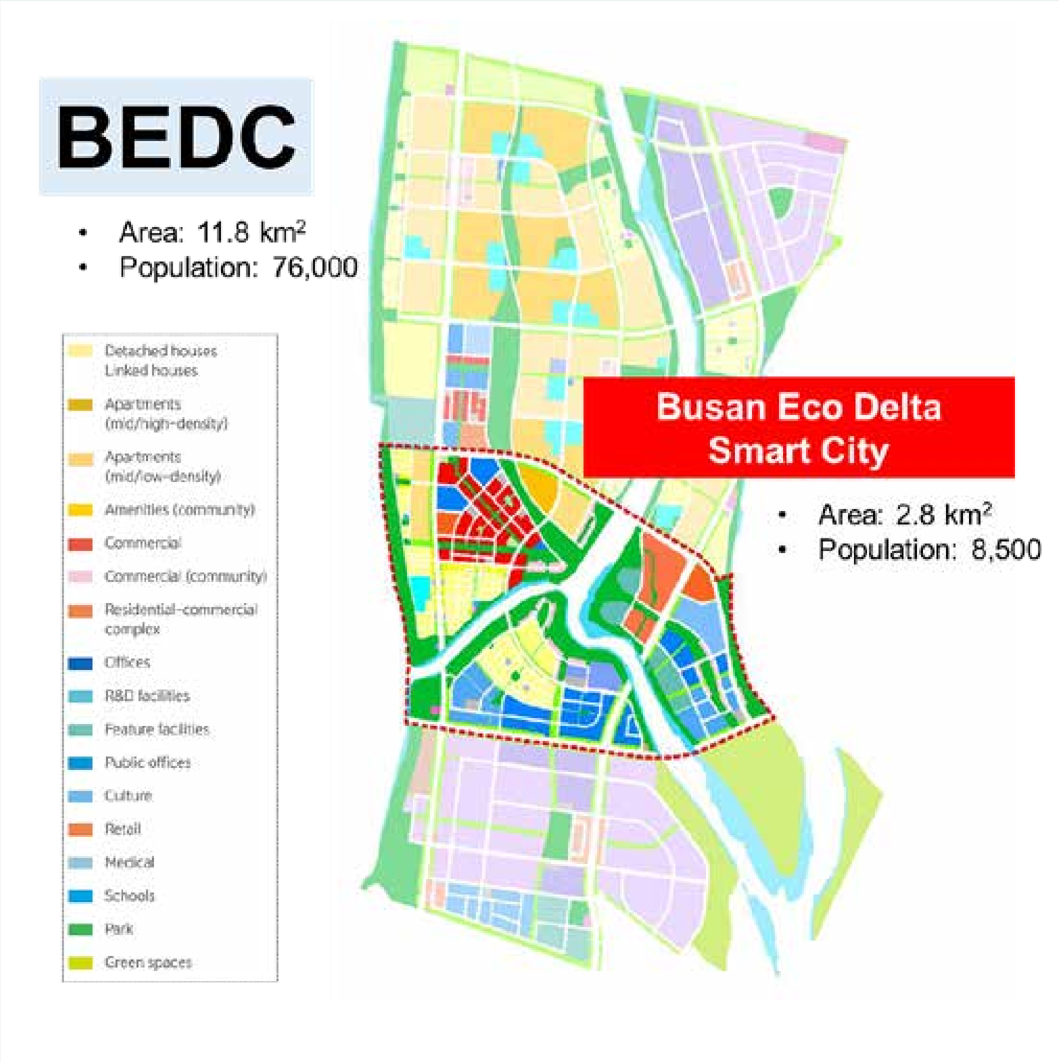
Busan Eco Delta Smart City

In 2018, the PCFIR of Korea announced a plan for the National Pilot Smart City in which the development of Busan Eco Delta Smart City (BEDSC) was included. The main purpose is to present future smart city models and create innovative industrial ecosystems while freely demonstrating and integrating the 4IR technologies[2]. Located in the center of BEDC (see Figure 2), BEDSC

1. K-water. 2018. Busan Eco Delta Smart City Master Plan.
2. Smart City Korea. 2021. Busan Eco Delta Smart City [Online]. https://cutt.ly/jU0wDVL (Accessed on 29 September 2021)

development aims to adopt smart 4IR technologies for achieving quality of life for citizens' and facilitate inclusive growth and fair opportunity in environment, safety, education, and culture[3].

Figure 2. Map of Busan Eco Delta City and Busan Eco Delta Smart City
Source: Modified from K-water (2021)[4]



Since the development has started from scratch in an open area of 2.8 km^2, specific urban challenges from every aspect in the city of Busan as well as general ones in and outside of Korea were considered when planning BEDSC development. These include environmental issues, population decrease (Busan/Korea and some developed world) and growth (most developing world), global competitiveness, etc. Consequently, ten innovative strategic objectives were set for BEDSC development in which Smart Water is included (see Figure 3). Thus, more than 100 smart technologies in water, safety, energy, mobility, health, education, and living will be applied in the entire smart city, which will make BEDSC a living testbed for smart 4IR technologies R&D[5].

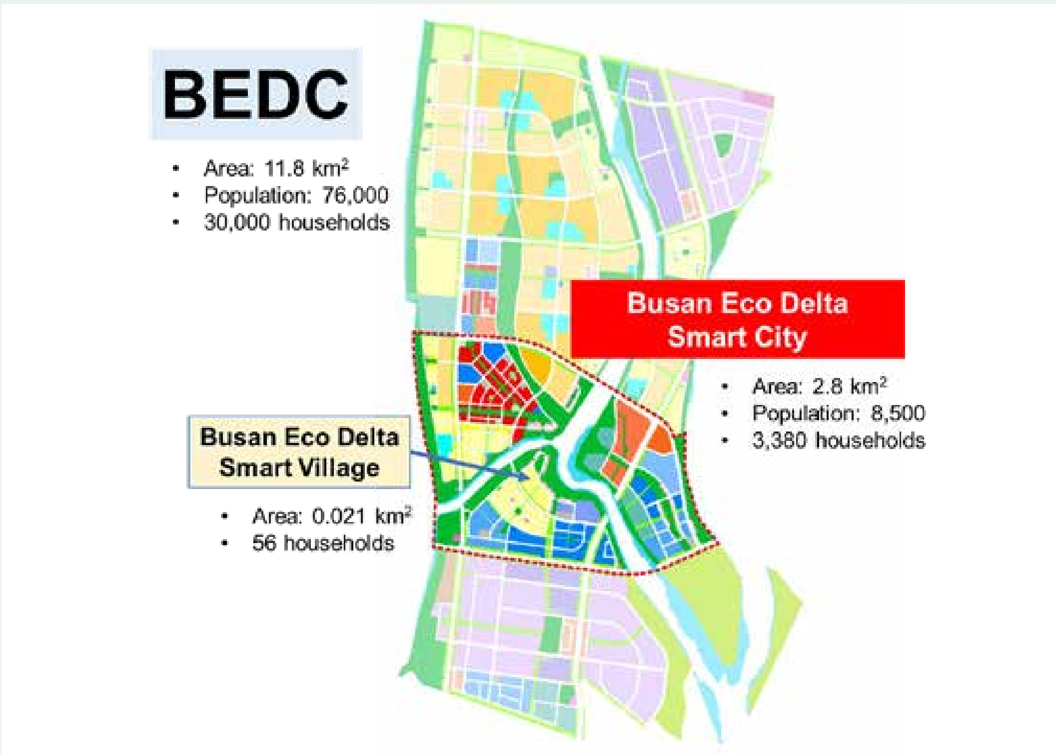
3. K-water. 2018. Busan Eco Delta Smart City Master Plan.
4. K-water. 2021. [Internal Document].
5. K-water. 2018. Busan EDC Smart City Concept Plan [in Korean].

Figure 3. Ten Strategic Objectives in Busan Eco Delta Smart City Development
Source: K-water (2018)[6]

Busan Eco Delta Smart Village

Since 2020, a special village with 56 new houses, called Busan Eco Delta Smart Village (BEDSV), has been built in BEDSC (see Figure 4). This is the first smart residential village where people will settle down in the National Pilot City of Korea[7]. Citizens will live in the houses and have hands-on experience with smart 4IR technologies. Afterwards, they will provide their feedbacks, which will be reflected when applying the technologies in the entire BEDSC. Therefore, this village will be the living lab in BEDSC.

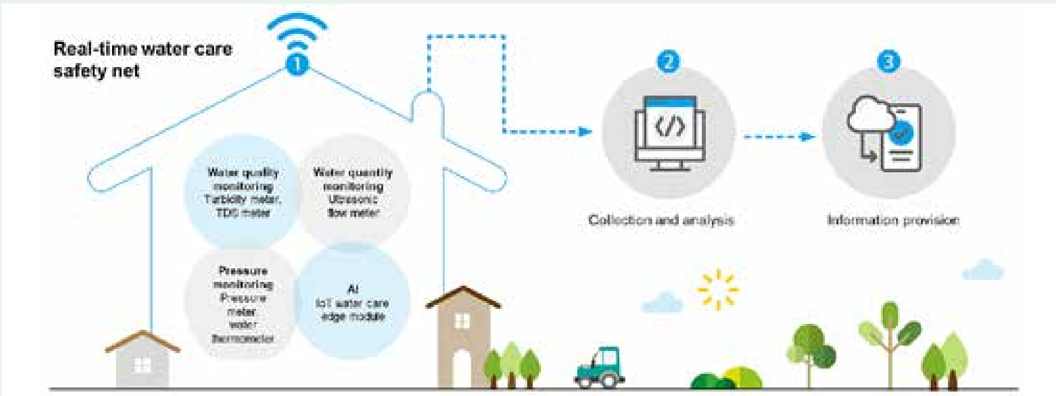
Figure 4. Map of Busan Eco Delta Smart Village
Source: Modified from K-water (2021)[8]



6. K-water. 2018. Busan Eco Delta Smart City Implementation Plan (Summary) [in Korean].
7. Smart City Korea. 2021. [Busan] Introducing Busan Eco Delta Smart Village [Online]. https://cutt.ly/rU0eoZ8 (Accessed on 29 September 2021)
8. K-water. 2021. [Internal Document].

BEDSV is also referred to as a Water Energy Science Village because its specialized features of applying water and energy technologies in its housing complex. Clean water produced from a decentralized smart water treatment plant will be distributed to each building. Afterwards, water quality such as turbidity and total dissolved solid (TDS), quantity such as water flow and pressure in each house will be monitored and analyzed through real-time water care safety net so that residents can freely drink and enjoy tap water with comfortable water pressure at home (see Figure 5). Moreover, BEDSV will be the first housing complex in the nation to acquire Zero Energy Building (ZEB) Level 1[9]. Renewable resources such as water-thermal, geothermal, and solar energy will be used in the buildings.

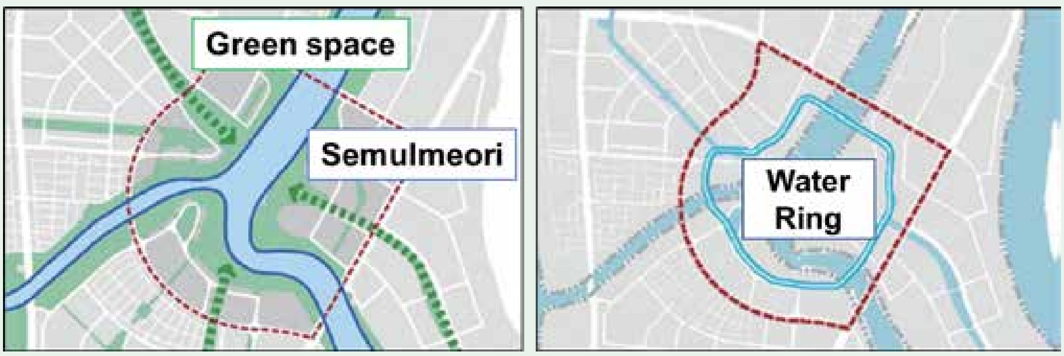
Figure 5. Real-Time Water Care Safety Net in Busan Eco Delta Smart Village
Source: K-water (2020)[10]



Eco-friendly waterfront city to enjoy the richness of the true nature

In the center of BEDSC, there is a geographical setting called Semulmeori where three natural streams of water (West Nakdong river, Macdo river, and Pyeonggang stream) meet. BEDSC development chose Semulmeori where people, water, nature, and city would be interconnected[11]. Green spaces and artificial water rings will be constructed along Semulmeori so that ecological as well as cultural and leisure activities can be thriving in this central area, surrounded by 54 km of waterfront (see Figure 6).

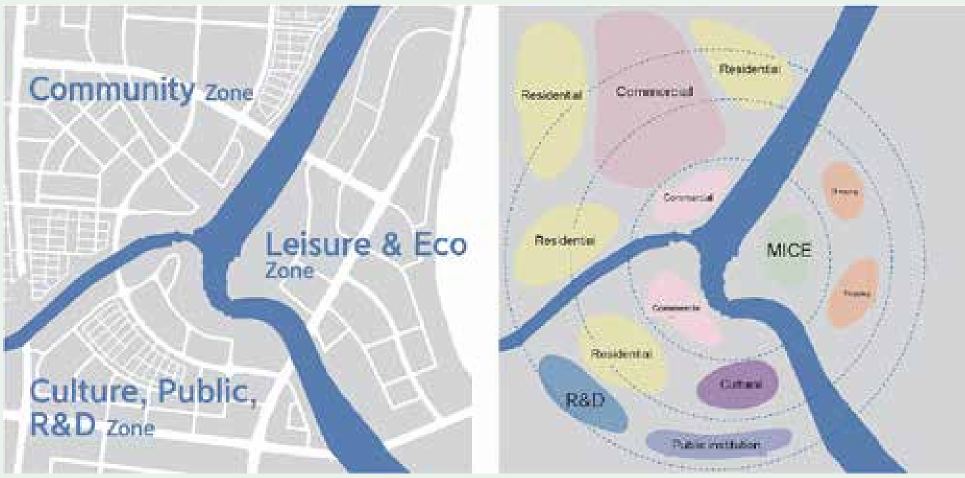
Figure 6.Green Space and Artificial Water Ring Along Semulmeori in BEDSC
Source: K-water (2018)[12]



9. In 2017, Zero Energy Building certification was enforced in Korea in accordance with the Green Building Construction Support Act. The certification has five levels regarding energy independence of the buildings. ZEB Level 1 is given to the buildings with more than 100% energy independence, which signifies higher energy generation than consumption in the buildings.
10. K-water. 2020. Future that You Experience the First: Busan Eco Delta Smart Village [in Korean].
11. K-water. 2018. Busan Eco Delta Smart City Master Plan.
12. K-water. 2018. Busan EDC Smart City Concept Plan [in Korean].

Moreover, commercial, cultural, and residential districts as well as R&D zones will be integrated around Semulmeori, which will make BEDSC more attractive and livelier (see Figure 7). A commercial and business district will be located with an 8 m wide, 1.2 km waterway running through it, and a district with an area of 0.69 km^2 will be designed into a multi-functional culture and leisure district[13]. The roads with priority for pedestrians will be constructed to connect residential areas in the 4.6 km smart community street, and bicycle roads with a total length of 48 km will be built to help promote public transportation. These roads will make access to rivers and parks in less than five minutes. Consequently, BEDSC aspires to be a city with an optimal arrangement of nature, scenery, and culture along the waterside by maximizing the value of waterways. In the city, work and leisure would balance well, and people would be able to enjoy walking and running while appreciating and preserving ecological values.

Figure 7. District Planning Along Semulmeori in Busan Eco Delta Smart City
Source: K-water (2018)[14]



Busan Eco Delta Smart City Platform[15]

In conventional smart cities, data platforms were separately developed and operated by each service and infrastructure. These separate platforms incurred high development costs as well as difficult application and validation of new ideas. However, BEDSC itself will behave as an unrestricted convergence platform where open data can be collected and shared among services and infrastructure in the city (see Figure 8). Moreover, digital twin technology will establish an augmented city platform of BEDSC (see Figure 9).

13. K-water. 2018. Busan Eco Delta Smart City: Master Plan Summary.
14. K-water. 2018. Busan EDC Smart City Concept Plan [in Korean].
15. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Figure 8. City as Platform in Busan Eco Delta Smart City
Source: K-water (2018)[16]

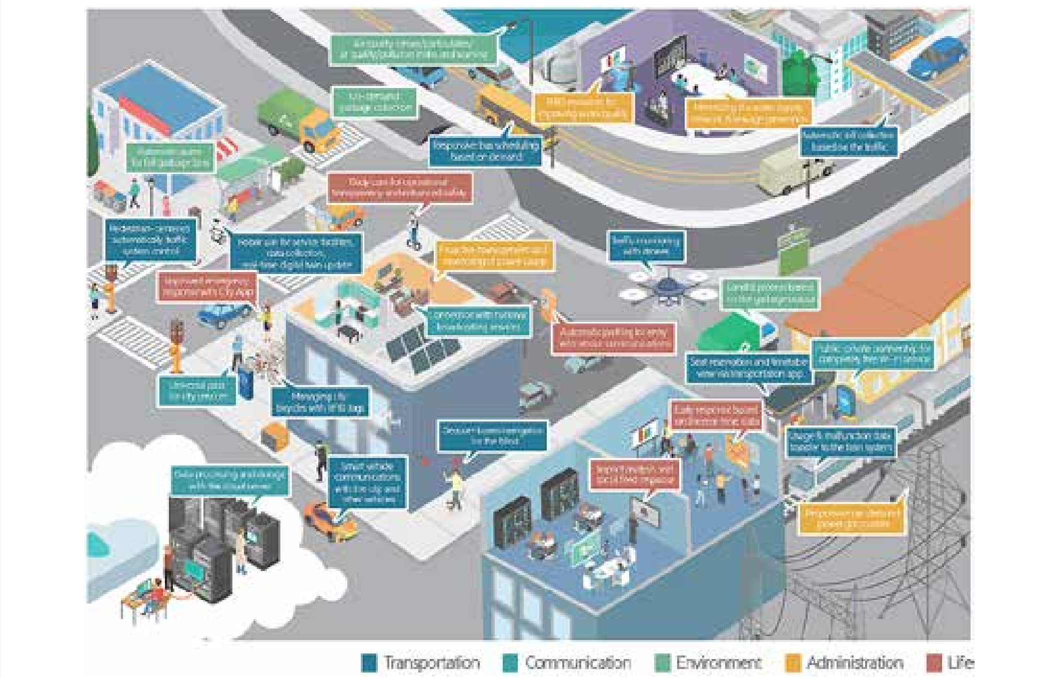
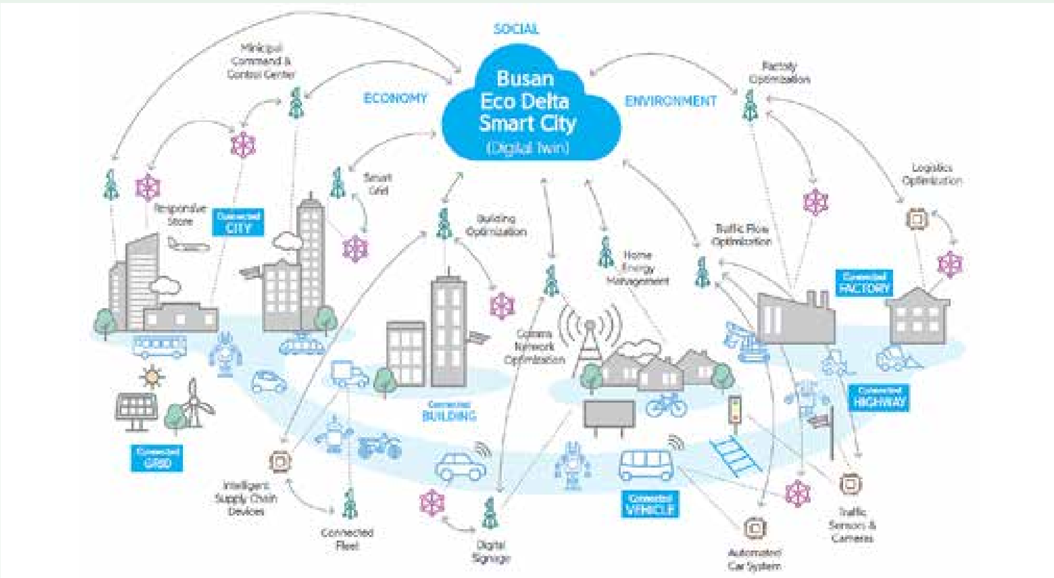


Figure 9. Application of Digital Twin Technology in Busan Eco Delta Smart City
Source: K-water (2018)[17]



K-water's 50-year water management expertise and know-how in Busan Eco Delta Smart City

BEDSC will showcase the collection of water management technologies from K-water's 50 year-expertise and know-hows, which will facilitate natural water cycle restoration in the city. Smart water infrastructure and services will be provided all around the BEDSC, such as precipitation forecast and urban water-related disaster response systems, Low Impact Development (LID) infrastructure and services, stream quality improvement infrastructure and services, smart

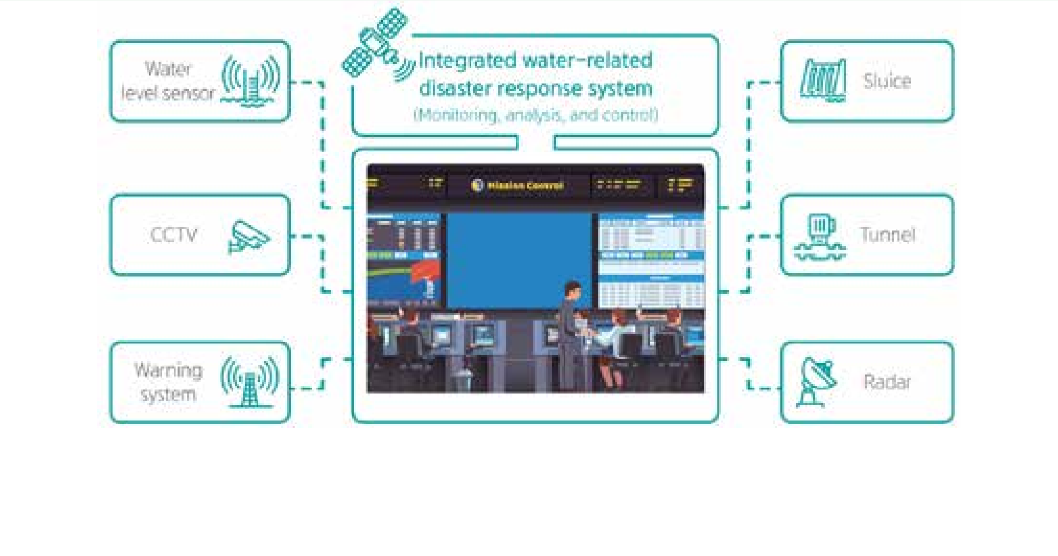
16. K-water. 2018. Busan Eco Delta Smart City Master Plan.
17. K-water. 2018. Busan Eco Delta Smart City Master Plan.

water treatment plants, SWM infrastructure and services, and water recycling systems (see Table 1). Moreover, for the first time in Korea, renewable energy based on water-thermal energy will be implemented for heating and cooling (see Figure 10).

Table 1. Smart Water Infrastructure and Services in Busan Eco Delta Smart City
Source: K-water (2018)[18]

Smart water infrastructure and services	Example
Precipitation forecast and urban water-related disaster response systems	Water level sensors CCTVs Warning systems Radars Sluices Tunnels
LID infrastructure and services	Permeable paving Bioswales Constructed wetland Rooftop gardens Rain gardens Percolation trenches
Stream quality improvement infrastructure and services	Eco-filtering system
Smart water treatment plants	Small-sized multi-story water treatment facilities
SWM infrastructure and services	Block flowmeter systems Water quality gauges Water leak detectors Automatic drains Water-NET operation/management system Information apps Water quality display boards Drinking fountains Water coordinators Water doctors
Water recycling systems	Highly advanced wastewater treatment plants

Figure 10. Water-Thermal Energy Supply in Busan Eco Delta Smart City
Source: K-water (2018)[19]



18. K-water. 2018. Busan Eco Delta Smart City Master Plan.
19. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Advanced urban flood response system

In BEDSC, there is continuous analysis of localized rainfall around the city with high-precision small precipitation forecast radar and preparations for flooding. These radars are connected to a data platform. This will allow emergency resilience in the smart city. Given the increasing flood risk due to climate change, the early detection system based on the water management platform will forecast a 6-hour lead time to flooding.

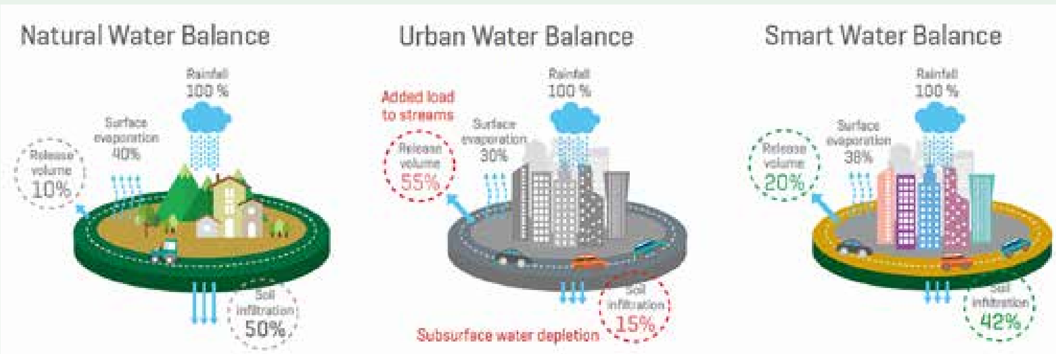
Moreover, there is continuous monitoring of water infrastructure, such as the water level, sluices, and drain system in link with the cross-city operation center for implementation of the integrated water-related disaster response system. This includes the installation of 70 sensors and 10 CCTVs for real-time data collection and monitoring, along with the forecast, analysis, and warning systems against flooding, drought, and water contamination.

Figure 11. Integrated Water-Related Disaster Response System
Source: K-water (2018)[20]

Introduction of Low Impact Development (LID)

Controlling the impervious areas to restore the water cycle will be part of the comprehensive water cycle management in BEDSC to tackle various issues arising from rainwater runoff in urban areas.

Figure 12. Smart Water Balance Concept
Source: K-water (2018)[21]



20. K-water. 2018. Busan Eco Delta Smart City Master Plan.
21. K-water. 2018. Busan Eco Delta Smart City Master Plan.

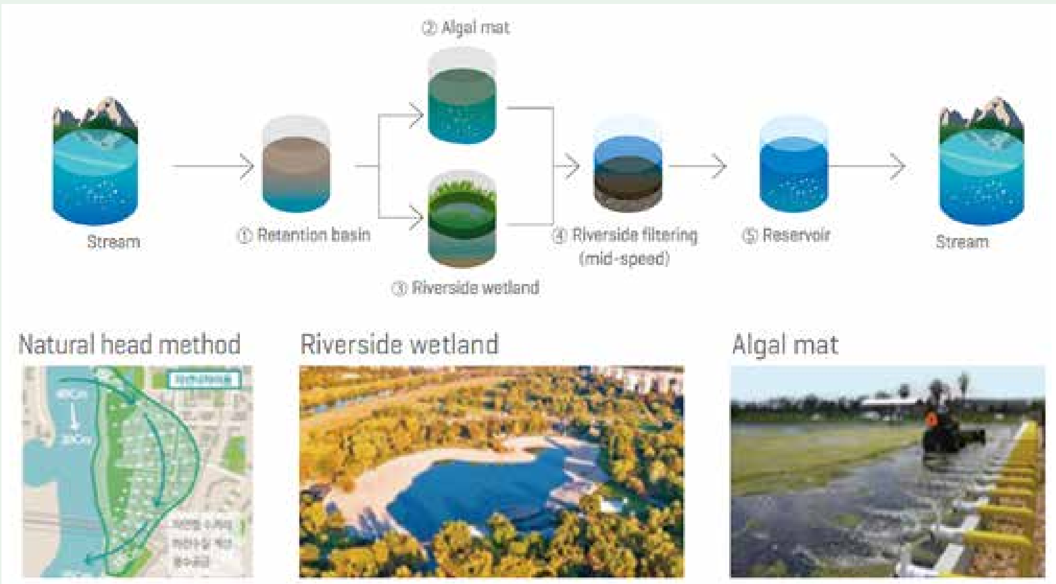
Water quality improvement of city stream

BEDSC includes the river delta and waterfront environment, as well as the Pyeonggang stream and Macdo river that flows through the city. The eco-filtering system aims to improve the water quality of these two waterways, with plans to turn the area into a water cycling park later. The Smart Water Management (SWM) technology will be used with the entire water supply process to obtain real-time quality information and to build the pollution management system.

There will be custom-built, green infrastructure for water cycling and recovery in the city connecting the roads, parks, riverside public facilities, and buildings to reduce non-point pollution that is common in urban basin areas.

BEDSC will achieve its status both as an international waterfront city and a national pilot project by improving the water quality of the two waterways crossing the area, Pyeonggang stream and Macdo river, to Class 2 or better.

Figure 13. Eco-Filtering: Key Technology and Process
Source: K-water (2018)[22]



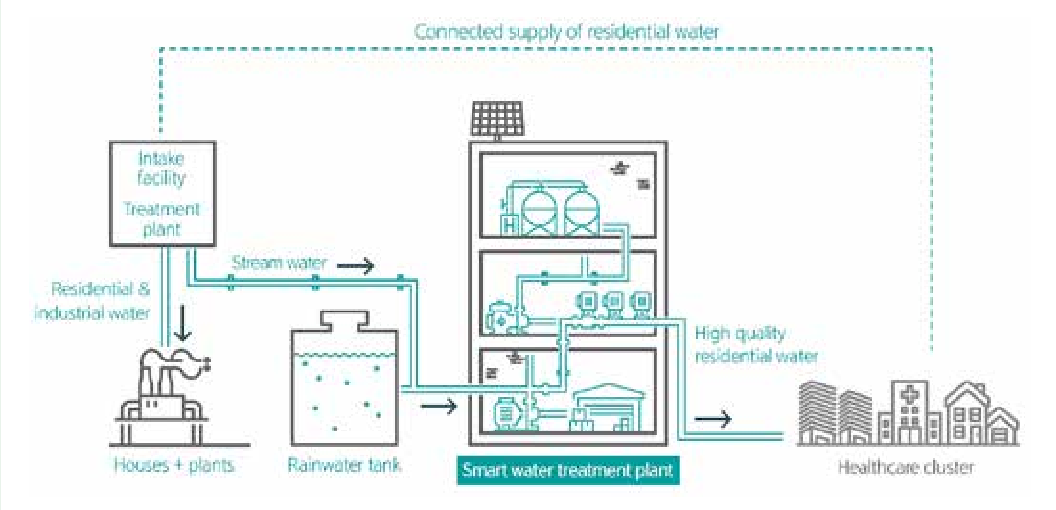
Smart water treatment plant

In the current water supply system in Korea, purified water is delivered to the final consumer from a large water treatment facility near the water source. While the conventional water supply system travels a long distance through tunnels, it is exposed to various risks, such as water leakage and water pollution.

To solve these problems, BEDSC is planning to build advanced small-scale treatment facilities inside the city. It will help reduce water loss and the use of chlorine, ensuring the quality of drinking water.

22. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Figure 14. Smart Water Treatment Concept Design
Source: K-water (2018)[23]



Smart Water Management (SWM)

The SWM system to be implemented in BEDSC uses a scientific approach to converge and manage water resources and the entire water supply cycle of purification, distribution, use, and reuse.

SWM technology will allow access to live information on water quality and quantity throughout the water supply process and to provide user-centric services. This includes ICT application in water supply processes from source to tap for real-time monitoring and remote control of water quality and quantity, as well as smart meters installed in households to provide data about amount used and enable other assistive services, such as the leak alarm and motion detection.

The SWM will be a complete water management model that expands water management from resource-centered to all areas of water flow, aiming to secure the reliability, safety, and efficiency of water supply by designing and operating the Smart Water Grid (SWG).

Figure 15. Smart Water Management (SWM) Design
Source: K-water (2018)[24]

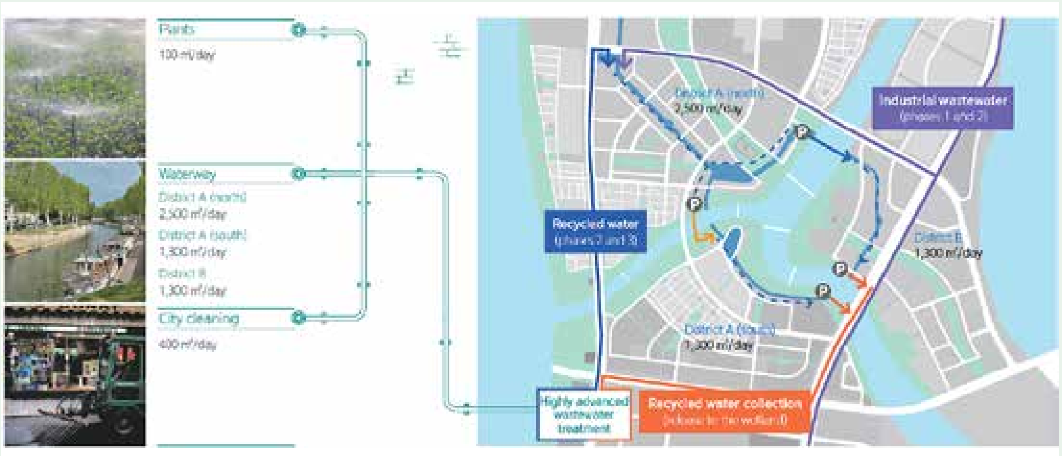
23. K-water. 2018. Busan Eco Delta Smart City Master Plan.
24. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Water recycling system

Wastewater from households and restaurants in BEDSC will be processed through an advanced water treatment system, and the treatment facilities will be equipped with reuse pressure systems. A recycling facility will be built in the sewage treatment plant with dedicated tunnels and a pressure system to supply and recover reusable water.

The complete wastewater reuse policy in BEDSC will be a proactive measure to protect water rights and counter water shortage problems. In BEDSC, 10% of wastewater generated in the city will be reused. Wastewater will be treated in an economically friendly way and reused for main waterways (91.1% of reused water), gardening (7.1%), and cleaning (1.8%).

Figure 16. Water Reuse Concept Design
Source: K-water (2018)[25]



Heating and cooling for the city using hydrothermal energy

BEDSC will offer a showcase of various water technologies incorporating the surrounding waterways. The city will utilize renewable water-thermal energy from differing temperatures of rivers and wide-area water sources to make the city eco-friendly for heating and cooling and reducing fossil fuel consumption.

Key Performance Indicators for Busan Eco Delta Smart City

KPIs for BEDSC were developed to achieve the vision, "a place of innovation and international leadership". The KPIs consists of six core objectives with 28 indicators to prevent and tackle current urban issues by fostering 4IR technologies and improving quality of life (see Table 2). With the KPIs, BEDSC would be a space where nature, people, and technology come together.

25. K-water. 2018. Busan Eco Delta Smart City Master Plan.

Table 2. Key Performance Indicators for Busan Eco Delta Smart City
Source: K-water (2019)[26]

Urban issue	Key Value	Core objective	KPI	Solution
Natural disasters	People	1. 5 years longer healthy life	1. To improve the water quality of Pyeonggang Stream and Macdo River to Class II or better	Water quality management
			2. Early flood detection - 6 hours ahead	Flood forecasting
			3. Reduction of earthquake early warning time to 20 seconds or less	Surface ground monitoring
Social disaster			4. Lowering of road accident rate to under 46%	Road accident prevention
			5. 100% complete early fire response in 5 minutes	Fire prevention and response
			6. 25% reduction in 5 major crime rates	Crime prevention and response
Health			7. 4.5-year increase in average life expectancy	Improved pedestrian zone
			8. Plus 3 years in healthy life expectancy	Smart healthcare
Living environment		2. 50 : 50 work & life balance	9. 76.16 m^2 of park space per capita	Recreational space
			10. 20,000 m^2 of festival street (40 m wide, 500 m long)	Culture/festival street
			11. 100% ICT-based learning	Smart education
			12. 15% reduction in time on housekeeping	Home IoT
Workplace environment			13. 40 weekly working hours	Smart office

26. K-water. 2019. Key Performance Indicators for Busan Eco Delta Smart City.

Urban issue	Key Value	Core objective	KPI	Solution
Transportation	Nature	3. 20% more renewable energy	14. 50% reduction in carbon emissions	Electric vehicle; road restructuring
Renewable energy			15. 120% of required power from renewable sources	Water-thermal energy; hydrogen fuel cell; photovoltaics, ESS
Construction			16. Zero-energy houses for 56 homes	Zero-energy housing zone
Water		4. 100% recycling rate	17. 100% wastewater reuse	Wastewater reuse, etc.
			18. 20% reduction in water usage and unused waste per person	SWM
			19. Impervious area down to under 15%	LID
			20. 16.5% of required power from wastewater-thermal energy	Sewage heat energy
Waste			21. 35% of required power from SRF	Incineration heat energy
Life-related services	Technology	5. 125-hour savings a year	22. 5 hours less waiting for medical consultation	Remote diagnosis
			23. 21 hours less spent in administration	e-Government
			24. 35 hours less spent on providing security and safety annually	City safety
Transportation			25. Over 20% of mobility enabled by bicycles	Shared bicycles
			26. 4 hours saved annually to find parking space	Smart parking
			27. 60 hours less time wasted on road annually	Smart traffic lights & smart road
Construction & innovative industrial ecosystem		6. 28,000 new jobs	28. 28,000 new jobs	Smart tech applications & city development; startup supports (acceleration/ incubation); validation & commercialization; R&D project development

Ciudad Juarez (Mexico)

Case study proposal: Ciudad Juarez, Mexico smart network for meter reading and pressure control management

Oscar Ibáñez, Jesus Lazo, Ramiro Meza, and Aníbal Miranda

Ciudad Juarez (Mexico)

Abstract

Ciudad Juarez, Mexico, is located on the largest desert latitude of the globe. It is part of a twin cities bi-national community with its twin city of El Paso, Texas, USA, integrating around 2.5 million people sharing the same two aquifers.

Our main concern and what motivated this smart project is reducing the Non-Revenue Water (NRW) while maintaining our current 24/7 service. To meet these two premises, we designed a master plan to reduce water loss by implementing technological changes that allow us to get modern technologies, achieve our main goals, and be ready for further advances with other sensors installed on our water network.

We also designed a financial master plan to fund an initial and internal smart network. The strategy was to capture incomes due to a more accurate registration of our most significant water use as very few accounts mean a considerable quantity of incomes according to our Pareto analysis of users-consumption-payment optimal figures.

Presently, we have a smart water infrastructure running which is reading 7,000+ smart meters every hour and 40 pressure control points reducing flow during the night; we funded this project through billing increments and savings because of NRW reductions.

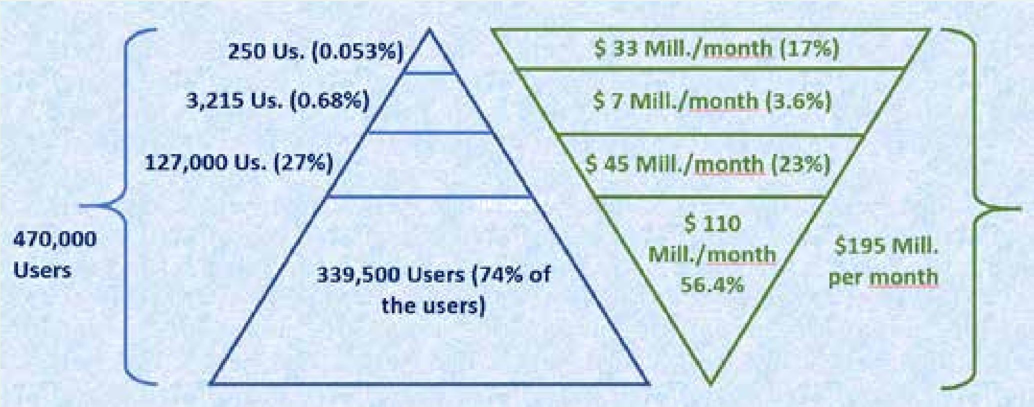
Introduction

Our starting point of the Key Performance Indicator (KPI) called Non-Revenue Water (NRW) was around 47% which was a bad KPI figure; at the same time, however, it means a double improvement opportunity. If we could reduce the NRW, we can increment our billing and reduce our operating costs. To work in both directions, we decided to implement new metering technology associated with a Radio Frequency (RF) fixed network with the capability to read in an hourly base water meters and pressure sensors. Additionally, we installed the necessary equipment to reduce water loss through some pressure control projects.

After some pilot projects that used different smart meters and reading systems, we finally decided to move forward looking for the best of the critical components of a smart network: extremely accurate meters, no moving part meters with a Ratio of at least 400 to get more incomes, and an automatic metering infrastructure (AMI), sometimes called fixed network reading system with the capability to read other sensors like leaks detectors or pressure sensors.

Our objective was to get enough funds to advance with new technology without incurring debt. We did a Pareto analysis of the number of users against income (see Figure 1). It was fundamental to define the way to go in terms of quantities and time frame for this ambitious project in a top-down sense, getting funds to finance the next stage.

Figure 1. Pareto analysis showing number of users associated with the corresponding billing in Mexican pesos.



We did not cover all the users, but we were able to track those that are most profitable for us and the best in terms of billing.

This benefit allowed us to buy meters, an RF network, and a pressure control system. The savings of water in some districts meant savings on energy, better pressure in other areas, and a reduction of the volume of water that we were losing before. Thanks to this project, we were able to recover and sell to other users.

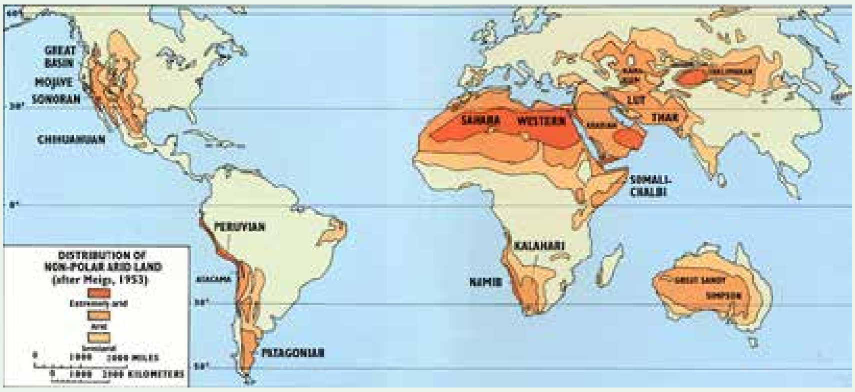
Characteristics of the city

Ciudad Juarez gets its fresh water from two transboundary aquifers, named 'Hueco' and 'Mesilla', both shared with the USA (USGS, Transboundary Aquifer Assessment Program (TAAP), 2017).

Figure 2. Location of the two shared aquifers with the USA

Juarez is in the Chihuahuan desert, experiences very dry weather with a maximum average temperature of 40.9°C, and a minimum average temperature of -2.6°C. They experience a rainy season in summer. The Chihuahuan desert is at the same desertic latitude as the Sahara and Arabic deserts.

Figure 3. Worldwide North Desert Latitude
(USGS, Map of distribution of non-polar arid lands, 1997).

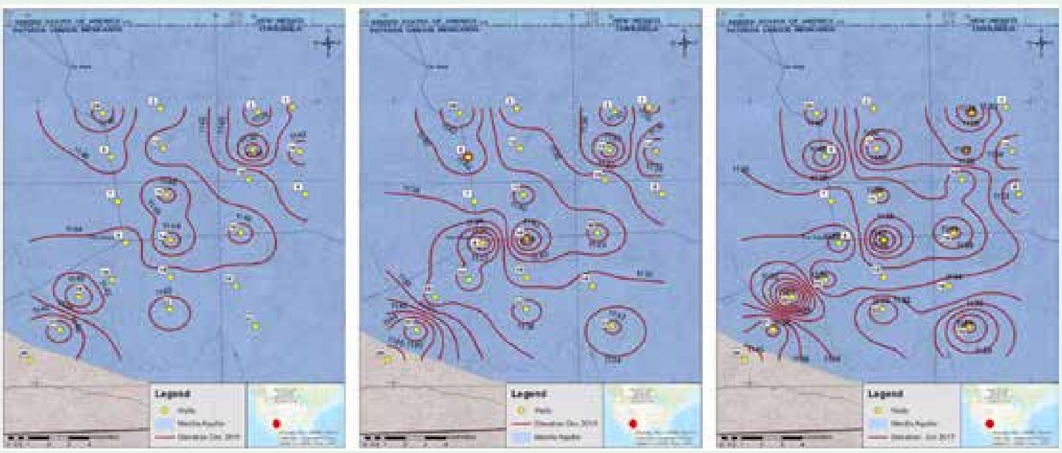


Ciudad Juarez has around 1,500,000 million settled people (INEGI, Censo de Población y Vivienda, 2020) and is served by the utility company named 'Junta Municipal de Agua y Saneamiento de Ciudad Juarez' (JMAS Juarez).

Despite being in a desertic latitude, JMAS Juárez provides water service 24 hours a day, 7 days a week. This utility company gets 100% of the fresh water from active water wells that pump around 200 million cubic meters per year at an annual growing rate of approximately 1% (JMAS, 2020).

Due to the extracted volume of water and the increment of the population, the hydric stress has been a critical concern for many years. Figure 4 shows the dynamic of levels of 'Mesilla' transboundary aquifers in 2100, 2013, and 2017 years (Garcia-Vazquez, 2021).

Figure 4. 'Mesilla's Aquifer Dynamic.



In April 2017, the state agency, named 'Junta central de Agua y Saneamiento del Estado de Chihuahua' (JCAS), devised a long-term hydric plan called, 'Plan Estatal Hídrico 2040' (PEH-2040), with eight strategic objectives. The hydric plan is a great tool to innovate on water distribution and conservation. The improvement of water metering and water controls has been one of the project resulting from the hydric plan.

Key water urban challenges addressed

Main reasons to move forward through Smart Water technologies
We devised a holistic solution which includes four components: (1) Smart meters with excellent accuracy, that are long-lasting, require minimum maintenance, and are read on an hourly basis to learn how users consume the water; (2) Pressure control valves (PCV) programmed with pressure level setting points for reducing the pressure during night and diminishing pipe leaks caused by overpressured lines (due to the typical nightly low water consumption); (3) An advanced metering infrastructure (AMI) to read meters and sensors continuously without people; and (4) A Cloud software platform implementation. Each of these technologies are beneficial for our NRW reduction purposes and for promoting water conservation practices of users with smart meters installed.

Starting point to pursue these objectives
With our focus on diminishing water losses, we define an estimation of our circumstances thanks to the most informed people in our utility company. We maintain a firm commitment to clarifying the concepts (see Table 1).

Table 1. First approach of NRW elaborated internally by JMAS in August 2019

TABLA DE AGUA NO CONTABILIZADA BASADA EN LA IWA, LA AWWA Y CONDICIONES ESPECIALES DE JMAS
Tabla inicial con estimaciones gruesas

					M3	LPS	%	
Volumen introducido al sistema m³/ año	Consumos autorizados	Consumo autorizado facturado m³/año	Consumo facturado medido	Controlado			43%	Agua comercializada m³/año
			Consumo facturado no medido	Cuotas fijas, consumo promedio			10%	
		Consumo autorizado no facturado m³/año	Consumo no facturado medido	Edificios publicos, escuelas publicas, oficinas de gobierno			7%	Agua no comercializada m³/año
			Consumo no facturado no medido	Parques publicos, reparto de agua en pipas por reportes de contingencias, cosumo en hidrantes			6%	
	Perdidas de agua	Perdidas aparentes m³/año	Consumo no autorizado	Tomas clandestinas			7%	
			Errores de medicion.	Medidores dañados, obsoletos, mal dimensionados, anomalias de medicion			6%	
		Perdidas reales m³/año	Erstimacion de fugas en la red	Fugas visibles, fugas no visibles			11%	Agua en perdidas y desperdcio real m³/año
			Disperdicio en limpieza de agua por temas de calidad	Desperdicio de agua en desfogues por reportes de agua con arena, desfogue en el arranque de pozos por los apagones de energia electrica			8%	
			Fugas en conexiones domiciliarias	Fugas provocadas por conexión directa de usuarios			2%	
Agua alumbrada			Concepto	Ejemplo			100%	

Elaboración inicial de esta tabla de ANC

ing. Ramiro Meza-Gestion de presiones y sectorización de la JMAS de Ciudad Juárez
Anibal Miranda, Consultor de la JMAS-Pulso del Agua Agosto del 2019

Valores conocidos
Valores estimados

To clarify the estimated figures shown in yellow, we got very accurate consumption measurements of the big users and public buildings; we bought electronic smart meters, sometimes called non-moving part meters (electromagnetic and ultrasonic), which commonly have wider measurement range than mechanical types.

We thought that if we could get good and frequent information about typical consumption of specific accounts, group of users, consumption per tariff, consumption per type of business, measurement of water in the inlet of private neighborhoods, etc., we could start a program of water balance in private neighborhoods to help us locate water losses.

Innovative smart water technology solution proposed

Another goal for hiring the consultant company was to develop the cloud platform which would receive readings and transform them into useful information for making decisions and training our people in smart non-moving parts meters, network technology, and software platforms.

We relocated people with technical backgrounds from several departments within our utility company to create a team and learned from the hired consultant company about this smart network technology. This interdisciplinary team was very successful; we had good rapport with the consultants, resulting in an effective implementation of this technology. Now, many of our people use the smart network technology terminology as everyday language and people are excited and engaged.

Scale

Our master plan was aligned with the Pareto analysis as described in the introduction of this report. The plan was to advance in three stages of no-moving part meters purchases. We decided to go with different brands and vendors to meet with our purchasing law to avoid giving advantage to a specific brand and to make sure that our needs were clear to all vendors. Thus, we generated an open and fair competition among vendors. We offered them down payments and paid quickly to assure safe commercial terms.

Timeframe of the smart water project

In 2018, we initiated the first stage of this project with only 250+ users. The selection of users was based on our Pareto analysis of users with higher incomes. The selection reflected the biggest consumers with old mechanical meters. High billing represented around 17% of our income, and the selected technology was Arad-made with cellular gateways. These meters resulted in an increment of 13% in the cubic meters registration compared to the average of the three previous years and their corresponding billing increment.

The second stage of the smart water project was in June 2019 when we acquired 3,000+ additional meters to replace old mechanical meters installed in commercial and industrial customers. The selected RF fixed network was Flexnet from the company Sensus; we deployed 15 RF collectors covering more than 70% of the city area where these big consumers were spread out. The first and second stages covered almost 3,500 users (only 0.73% of our customers that represented around 20.6% of our incomes); with these smart meters, we incremented their water registration and billing, so we did not need any loans. Overall, it was a very profitable project and allowed us to advance to the next stage, which is currently in progress.

KPIs and standards adhered to

Our lack of experience on these technologies and few international figures regarding experiences disappointed us. We found several cases of this type of project in a worldwide frame, but nothing relevant in Mexico or Latin America. We traveled to Albuquerque, New Mexico (US) to see a project of 100,000 smart meters working there. We had the opportunity to ask a water utility company directly about their experience implementing smart water networks.

We didn't find real examples of registration increment because of better meter accuracy of the electronic meters, so we decided to advance with no other figures than our numbers of billing increment and savings on water with the PC projects. We aimed to take advantage of the data coming from hourly readings.

Main results in terms of water consumption knowledge

With the cloud platform, our consultant company designed several dashboards and reports to meet our needs. We gained a lot of knowledge about water consumption. The figures which follow show several consumption profiles from our platform that reflect the hourly data readings:

Figure 5. Hourly flow graph of a specific district useful for planning water wells pumping

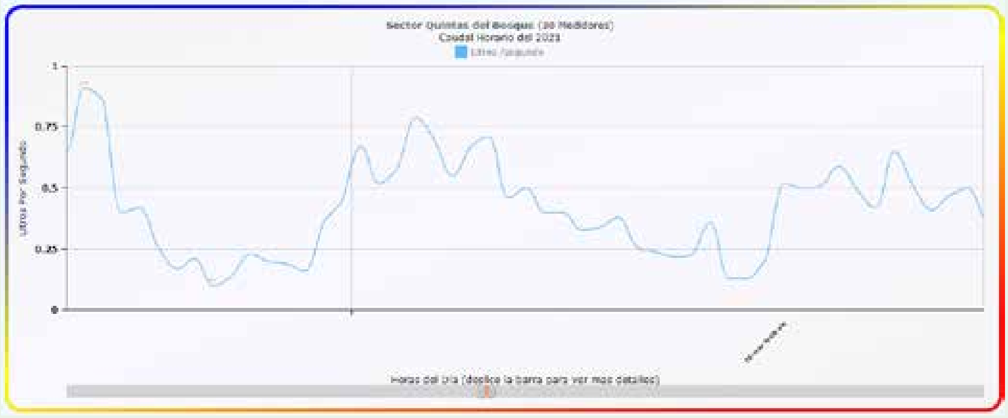


Figure 6. Daily consumption of a group of users corresponding in this case to the commercial group with smart meters, useful for better water distribution

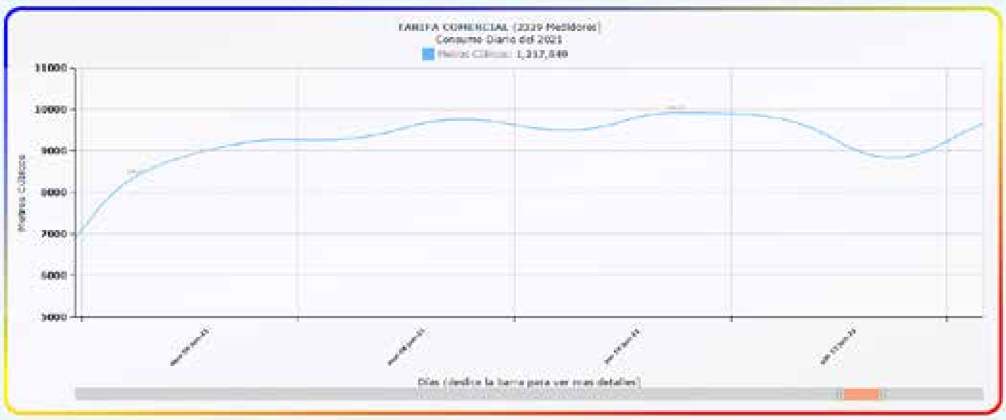


Figure 7. Monthly consumption of treated water of a specific account for planning our incomes

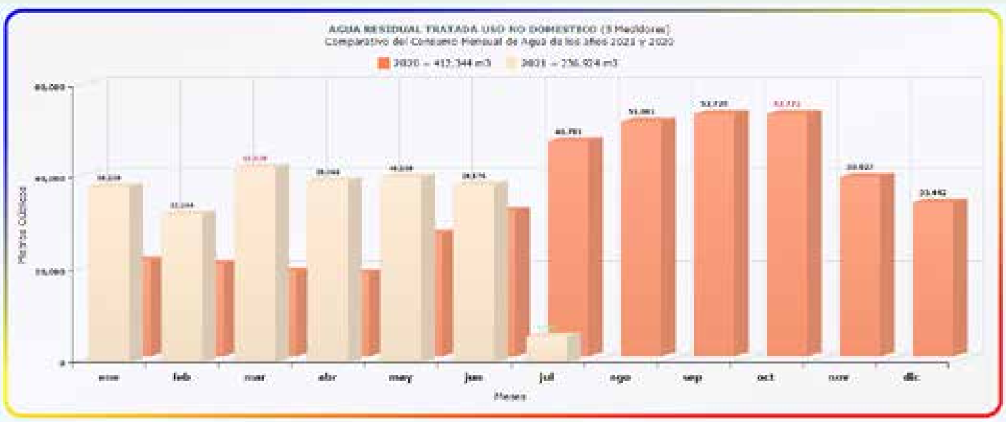
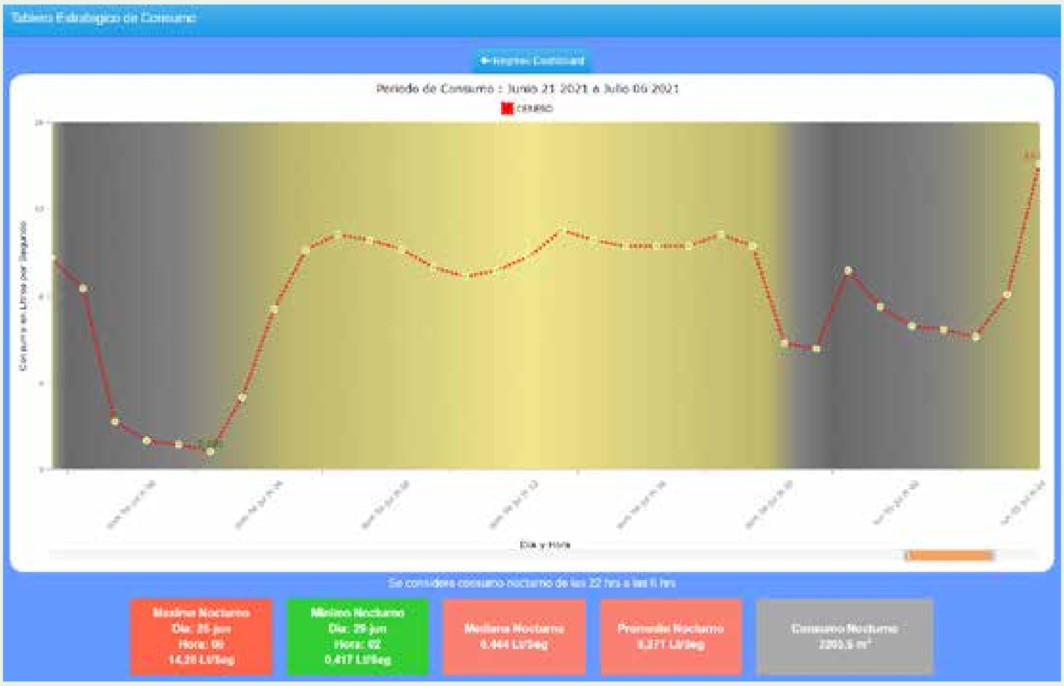


Figure 8. Hourly consumption of a specific account. In yellow, consumption during the day. In gray, nightly consumption. Useful for pressure control projects



Results from the pressure control systems

A representative case of PC was implemented in an area named, 'Riberas del Bravo'. This water district serves 15,000 water connections under a low-efficiency connection, is supplied by 2 tanks and 2 deep wells connected to the distribution pipelines. Additionally, irregular topography of the area causes high pressure and strong transitory phenomena.

Because of this situation, a pressure control pilot project was implemented with the international company SUEZ, installing smart meters at the outlet of the tanks, as well as single and double control points with pressure regulating and sustaining pressure valves.

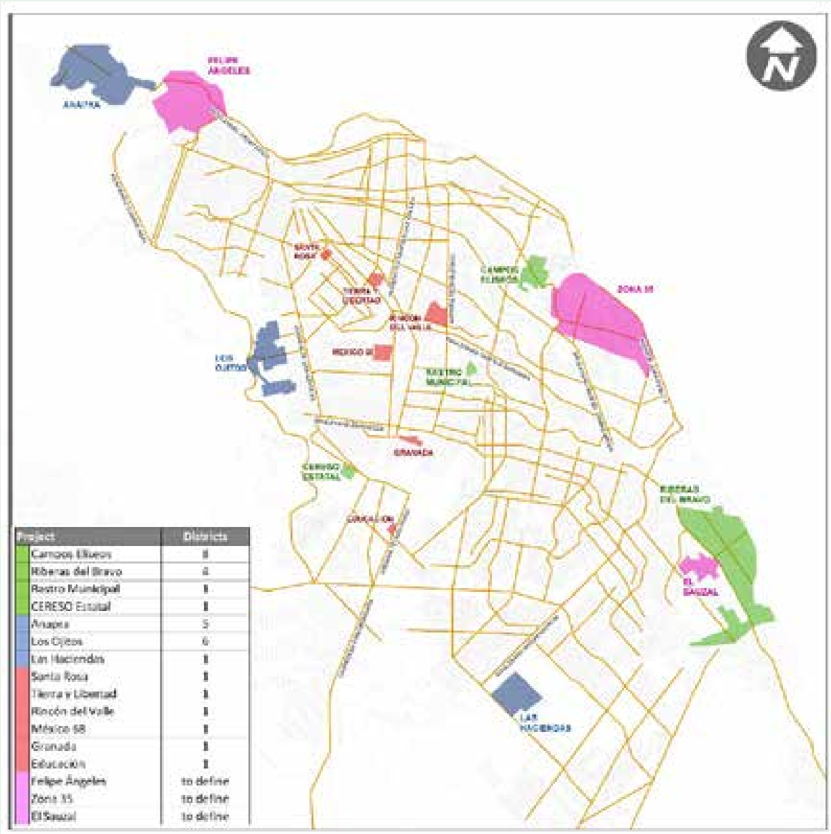
These valves were controlled using monitoring and control equipment, which allowed establishing of optimal pressure setpoints and the reduction of average service pressure and occurrence of transients. Minimum night flow rates were reduced by up to 80%. This project, 'Riveras del Bravo', by itself, represented an important saving of 1,047,370 m^3 in a year, which means around 0.5% of total water pumping in a year, and this volume was saved in only one of the four areas with this pressure control. See Figure 9 below.

Volume saved 2020 Y 2021		
District	Control period	m^3 saved
Campos Elíseos	16 months	88,421
Cereso Estalal	15 months	363,056
Rastro municipal	16 months	4,196
Riberas del Bravo	12,5 months	1,047,370
Summary	16 months	**1,503,043 m^3**

Figure 9. Volume saved in four districts between 2020 and 2021.

Now we are planning more pressure control projects in the city in zones where we estimate we can get better savings (see Figure 10).

Figure 10. Classification of districts; at present in green, to start soon in blue, short-term period in red and long-term period in pink.



In addition to the water savings, we gained important energy savings and reductions on the rate of broken pipes. In the last stage of this project, a double control bypass was implemented, integrated by a pressure regulating valve (PRV) with sustaining valve, which both allowed the volume of water to migrate from one district to the other, depending on the demand and it allowed us to shut off a deep well with an approximate flow rate of 30 lps.
Currently, 40 more districts in the rest of the city are in progress with a kind of pressure control system which obviously reduces NRW (see Figure 10). Our challenge is that in 4 more years, 90% of the city will be implementing some or all four pillars of the IWA related to NRW reduction. This could mean an overall efficiency of the city in the range of 70%.

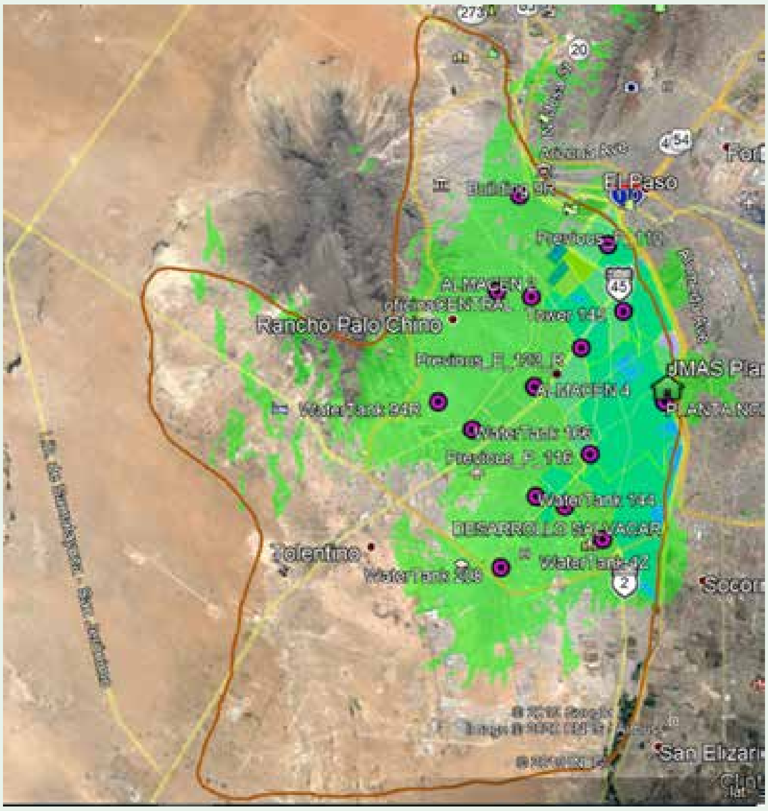
With this small but powerful smart network, we started the third stage of network. Now, we have received more than 70,000 hourly daily readings. We already own 40+ millions of hourly readings that allowed us to understand better the consumption of few users that represented a critical portion of the consumption and incremented our incomes.

Technical and non-technical requirements for the implementation of the smart water technologies

The technical requirements of the components were very well defined with the consultant company that specified the solution and the internal team appointed to get a successful story. Meter installation requirements were of issue because we were not very precise, and it had negative consequences. Issues related to the RF transmission were critical because our meters are installed underground in a pit with a metallic lid, reducing the distance to read.

Ciudad Juarez has very flat conditions, so the RF propagation study allowed us to cover around 70% of our served area with only 14 Radio gateway base stations. Thus, we could read in the second stage, 3,215 spread meters in a big area but still covered for the RF signals. This was considered a good reading for most of our biggest consumers.

Figure 11. Propagation study for the RF stage two with Sensus Flexnet network; municipality limits in red, estimated RF coverage in green

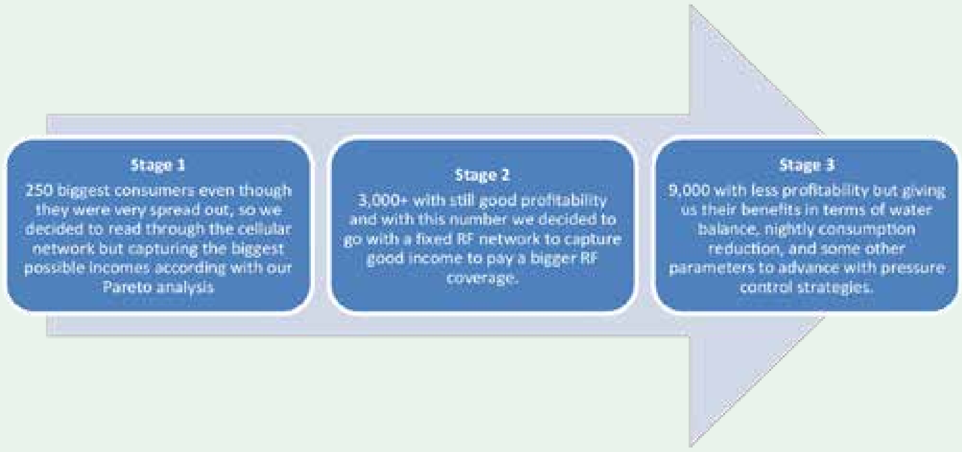


How we got funds to implement this ambitious project of Integrated Water Resources Management (IWRM)

To determine if we could get internal funds which would allow us to avoid external credits that carry both an additional cost and take a long time to get, we analyzed the associated cost of the infrastructure to see whether we could get enough income coming from the additional invoicing because of the better meter registration. We developed an excel file with historical readings of the mechanical meters which correspond to three years before using this technology; consumption was calculated month-by-month. Our initial estimation of registration was 10% because of the replacement of the old mechanical meters for new and very accurate electronic smart meters.

We analyzed the return of investment from different points of view, for every diameter, every tariff block that we call 'Grupo tarifario', and for every specific type of user that we call 'Giro'. Based on the historic consumption and potential increment, we determined an estimated return of investment of each of the consumer groups to calculate the internal financial support needed

Figure 12. Three stages of the implementation of the smart metering project



At the time of writing this report, we have 7,000+ smart meters throughout our three communication networks:

- The first 250 meters of stage 1 that we still are reading through cellular communication.
- 3,000+ meters of stage 2 read by a Sensus fixed RF smart network called Flexnet.
- 4,000+ meters read by Kamstrup Fixed RF network called Ready; project currently in progress of 9,000 corresponding to stage 3.

Main practical issues we found implementing this smart water project

There have been some practical and theoretical differences and issues found, some of which were positive findings.

Some positive findings

We thought we were going to find more obstacles from our users because their billing increased; however, as we went to the biggest consumers, they understood the critical issues of water conservation and accepted this technology. In some of the cases, they celebrated us for modernizing the meter infrastructure.

Other groups of consumers, however, like commerce or big residential consumers, complained about the consumption increments a month after this technology was installed. When we demonstrated the real consumption with hourly readings, however, they changed their attitude and promised to save water to avoid that additional increment.
We did not really have obstacles from the public, and this was mainly because we were widely announcing the project beforehand. We did an internal presentation to the utility labor union, as well as hosted some dinners to announce this project with chambers, Maquiladoras Organization, and more.

From the moment we started, we thought we were going to face internal obstacles, such as with our labor union, for instance, but we did not. Once they understood the project, asked what the benefits of implementing this technology were, we were able to explain how the meter-readings of big consumers would improve their working conditions; we assigned them more supervision tasks.

Another further advantage was the approach of several vendors in the market, giving us technical presentations and offering to test equipment and sell new technology as automatic valves, leak detection equipment, pressure control, etc.

The technology challenge was surpassed with certain difficulty. Ciudad Juarez has a high technological environment as there are more than 400 manufacturing facilities ('maquiladora industry'), many of which are involved in the high technology industry. There are good universities located here, as well as some research centers. Thus, you can find open-minded and educated people who are eager to learn. This environment proved very favorable for our project.

Some findings gave us valuable learnings

We thought at the beginning of this project that the RF propagation studies were not necessary, and we pushed back against vendors requesting about RF collector location. However, after some RF Studies of different vendors, we could verify how critical the geography is of where you are going to implement the project. As a result, we have had good experiences with RF communications.

We also thought that due to Ciudad Juarez's conditions and their underground meters and metallic lid over the register, it would reduce the RF reading performance. This proved to be a critical issue. Thus, we are changing our specs for future installation, changing lids to ruggedized plastic lids instead of metal.

Now we know the network performance depends not only on the smart meter, but rather, several factors are involved. These include whether the RF module is inside the meter or not; the RF power transmission inside the meters; the power of the RF collector and the height and gain of their antennas; the material of the lid covering meters in case they are installed in pits underground; and the geography of the city (among other factors). In Figure 13 we show the monitoring of the networks we had while writing this report.

Figure 13. Effectiveness and efficiency of the several couples'Smart meters<-> Smart Network'

As shown in Figure 13 above, the green line corresponds to the couples integrated by 'Aichi Tokei' electromagnetic meters with an Flexnet RF module where the antenna was outside the pit and they are read by Flexnet smart network. By contrast, the orange line refers to Sensus meters with a RF module located inside the meter reporting the reading through the same Flexnet network. In other words, the same network and same power of RF modules offer different performance depending on the meter antenna that is under or over the metallic lid. We have not had any experience with meters installed in pits underground with plastic lids over the registers. Still, we estimate the performance will be similar to those where the meter has an RF module with an external antenna. Hence, chances are our internal standards will change to plastic lids in future deployments and new accounts where we plan RF connectivity.

Summary of our results at this moment
Something especially important is that we implemented an MDM software customized to us through the consultant company with the purpose to read different meters with different networks. Now we are reading 5 couples in the networks:

- 60+ Arad ultrasonic meters Octave model (Ratio 400) with cellular gateways.
- 3,200+ Sensus water meters electromagnetic type model Iperl European version (Ratio 800) through the Flexnet network.
- 120+ Aichi Tokei electromagnetic meters model SU, through the Sensus Flexnet network.
- One Ultrasonic Badger meter e-series model is still under testing reading through LTE Cat-M network.
- 4,000+ Kamstrup meters model Flow IQ 2200 read by their network named ReadyAMI.

We have tested other brands or models of meters, like Omnimeter and Ally from Sensus company, gateways for sensors like the model Smart gateway of Sensus, and all reporting readings through Sensus Flexnet smart network.

Now we can say our smart network depends neither on one brand of meters nor on a specific RF network, vendors do not influence us, we specify our conditions, invite several vendors to explain our operations and requirements to receive the readings with a specific data format that we can interpret and add to our databases.

Regarding the RF licenses, we already have spectrums bands licensed to our utility in the next bands: Two bandwidth (one up and one down) on the 900 Mhz. range for Flexnet network, and a couple more in the 400 Mhz. range for Kamstrup network. We have a good spectrum availability to have a reliable smart water network infrastructure.

Challenges
After this positive experience, we plan to keep advancing with smart metering installations on profitable accounts. We have our master plan of district metering (DM) for water balances and pressure control based on the internal consumption.

We are planning to incorporate an online software module in our current platform to be aligned with the NRW concepts using the International Water Association (IWA) water audit methodology. We plan to follow and make the necessary adjustments for our master plan up to 2024 for an optimization related to a better metering and water distribution management.

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Heredia (Costa Rica)

Innovative technology for drinking water sediment collection: scaling from big to small cities in Costa Rica

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Heredia (Costa Rica)

Abstract

Urban watersheds are almost universally subject to degradation driven by changes in flow and sediment inputs from the streams. In urban watersheds (cities), sediment sources from channel erosion is a common response to altered urban flow conditions. To analyze how the sediment yield is managed in a large city in Costa Rica, defining the potential to scale its experience to smaller rural cities, we present an innovative technology implemented in a drinking water system. After the analysis of a preliminary operational cycle, we found that the Sediment Dynamic Multivortex (SDM) removes 76% of turbidity. To scale such innovative technologies, from big to small Costa Rican cities, we define several considerations. Particularly for the municipality of Turrialba, some ongoing steps are needed. For instance, experiences in the implementation of best watershed management practices related to field visits, exchange of knowledge, general diagnostic of local needs on drinking water systems are already in place. On the other hand, the current technology implementer (ESPH), together with technology designer Lucas Electrohidraulica (LE), has the potential to contribute through lesson learning, data sharing, and technical assistance, as well as through overall support of the upscaling of its watershed management experience–particularly in the case of ESPH regarding their water resource protection fee. The intellectual property of the innovation belongs to Lucas Electrohidraulica S.A. The equipment was developed by the industrial diver, Pablo Gonzalez Lucas, and the engineer, Gustavo Tellez.

Introduction

Four in five urbanites in large cities, around 1.21 billion people, primarily depend on surface water sources (McDonald et al, 2014). 80% of GDP is produced in cities globally, and there will be major economic repercussions if water security is not guaranteed (UNESCO, 2019). Thus, ensuring urban water security is an urgent challenge that may threaten the food of humanity, as well as economic, ecological, and national security if not properly addressed (Jimenez -Cisneros et al, 2014; Gerlak et al, 2018).

Urban water security reflects the dynamic capacity of the water system and water stakeholders in safeguarding sustainable and equitable access to adequate quantities of water with acceptable quality that is continuously physically and legally available to meet water demand at an affordable cost. In order to sustain livelihoods, human well-being and socio-economic development, it's necessary to ensure protection against water-borne pollution and water-related disasters, as well as preserve ecosystems in a climate of peace and political stability (UN-Water, 2013; Aboelnga, 2019).

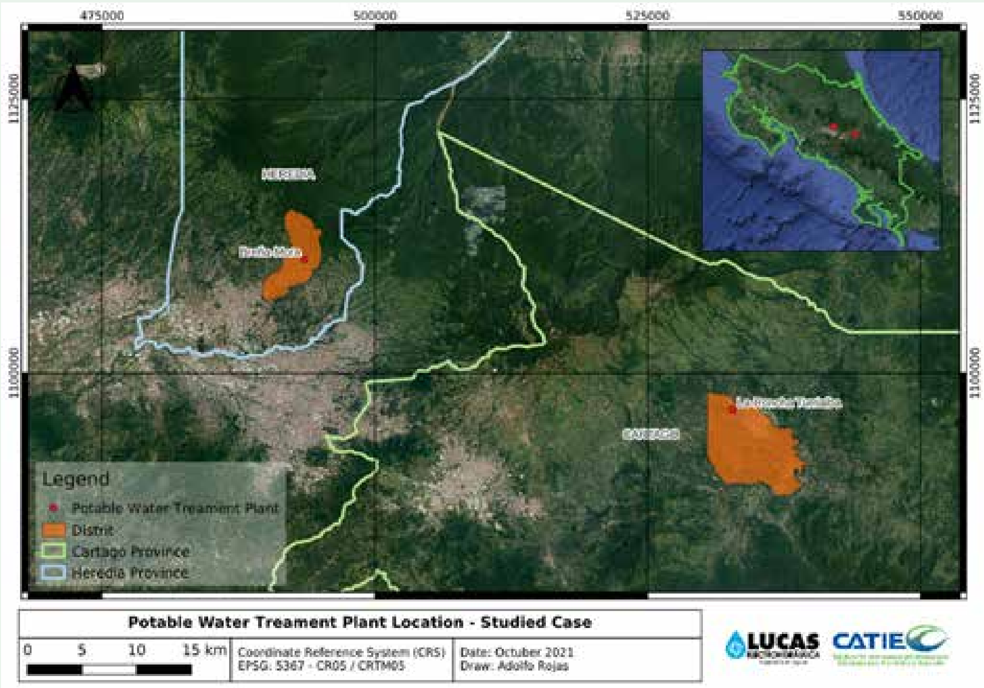
Streams with urban watersheds are almost universally subject to degradation, largely driven by changes in flow and sediment inputs from the watershed (Rusell et al, 2017). A major and widely documented sediment source is channel erosion, which is a common response to altered urban flow conditions (Chin, 2006).

Impacts of anthropogenic activities in water quality, with agricultural land uses (Ahearn et al, 2005) and population density (Holland et al, 2005) has been widely reported, altogether affecting sediment and nutrient loading

(McDonald et al, 2016). From a study of urban source watersheds for 309 large cities (population > 750,000), in the period between 1900-2005, it was concluded that watershed degradation has impacted treatment costs for 29% of cities globally, with operation and maintenance costs for impacted cities increasing on average by 53 ± 5%. Replacement capital costs are also increasing by 44 ± 14%, which leads to increases in water-treatment costs with real quantitative cost for hundreds of millions of citizens (McDonald et al, 2016).

Our case study seeks to analyze how the sediment yield is managed in the third largest city in Costa Rica, Heredia (World population review, 2021). Additionally, we explored the possibilities to scale the technological approach of such city in a small rural city, in Turrialba. Figure 1 shows the DWTP location in Breña Mora, part of the Enterprise of Public Services (ESPH) in Heredia, and the aqueduct of the small city to scale the technology, La Roncha, Turrialba, Costa Rica.

Figure 1. Location of the drinking water treatment plant, Breña Mora, Heredia and the small city to scale the technology, Turrialba, Costa Rica.



In Costa Rica, drinking water services are managed by the following operators: (1) Costar Rican institute of aqueducts and sewerage (AyA) serving 48% of the population; (2) Associations administering communal water supply and sewerage systems (ASADAS) serving around 26% of the population; (3) Municipalities serving 14% of the population, and the Enterprise of Public Services of Heredia (ESPH) serving 4% of the population; and (4) Rural Aqueduct Administration Committees (CAAR), covering around 6% of the population (Mora and Portuguez, 2020).

ESPH is an autonomous company that provides multiple public services and was incorporated under a private law. This company provides water, sewage, and electricity services to the province of Heredia. In Turrialba, the municipal aqueduct serves 20% of the population of Turrialba's canton. The remaining population is served by ASADAS and CAAR.

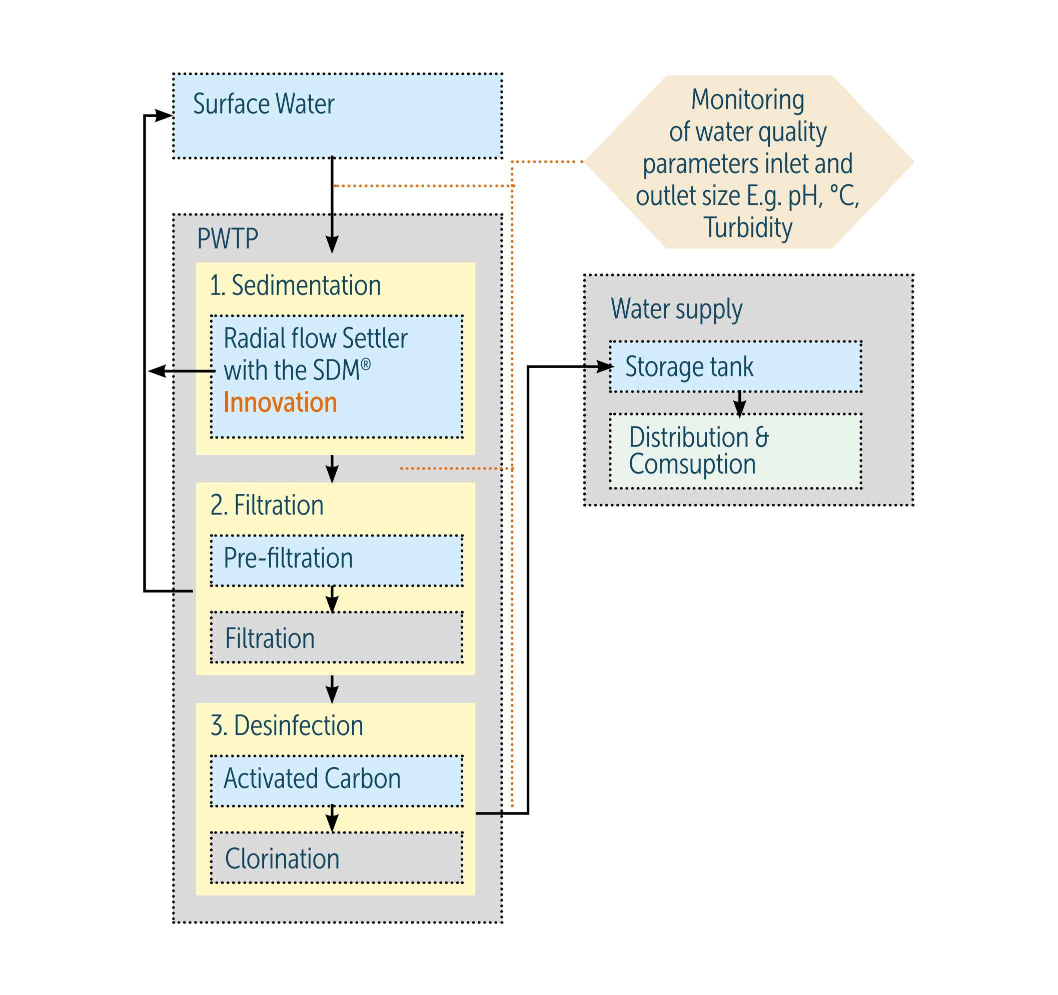
It is important to mention that in Costa Rica, 4.6% of the population with access to water supply is served from surface water resources, and according to the national inventory of water sources in 2015, 5.53 % of water resources corresponds to surface water. From these surficial water sources, 86.4% corresponds to rural cities or rural aqueducts (Mora Alvarado et al., 2016).

According to INEC (2011), the central canton of Turrialba has a total population of 69,616, and 91.6% of that population has access to a supply of drinking water. The "La Roncha Turrialba" aqueduct is an important part of the municipal drinking water system, serving around 1000 connections. It has been affected by sediment load at recurrent occasions. Figure 2 shows the water catchment of La Roncha, Turrialba's aqueduct.

Figure 2. La Roncha, Turrilaba's aqueduct water catchment

The Breña Mora drinking water treatment plant (DWTP), owned by the Enterprise of Public Services of Heredia (ESPH by its Spanish acronym), was designed, and built by Lucas Electrohidraulica (LE) company in 2018. The Breña Mora DWTP takes surface water and has a design which encompass a flow capacity of 40 l/seg up to 60 l/seg. The DWTP mainly serve 2 of 10 cantons of Heredia with 3000 connections of water for a population of approximately 12,000 people. This represents 4.64% of the total population supplied by ESPH (Mora Alvarado et al., 2016). This DWTP has an innovation technology patented by LE Company –Sediment Dynamic Multivortex (SDM) into the settler of sediment phase. Figure 3 shows the site conditions and the grey infrastructure of the water catchment of Breña Mora DWTP, as well as the flow diagram of water treatment in Breña Mora Aqueduct. The innovation adding to the Smart Water Cities paradigm is the "Sediment Dynamic Multivortex (SDM)" which is located in the sediment phase into the sediment chamber of the settler.

Figure 3. Drinking water treatment plant diagram (source: DWTP drawings by LE)



The Breña Mora DWTP has three main phases: (1) Quality and quantity of raw water; (2) Coagulation-flocculation process and sedimentation; and (3) Filter and disinfection system: Pre-filter, multigranular filter, activated carbon filter, and chlorination.

This DWTP differs from other systems by settler characteristics, which correspond to a wake vortex turbulence technology. The wake vortex is defined as turbulence which is gendered by the passage of the water through the corrugated sheet. In Figure 4, we can observe the sediment collected in the corrugated sheet.

Figure 4. Sediment collection on the SDM
The flow direction in the picture is from left to right (source: ESPH - Breña Mora).

LE's experience led them to observe that working with slightly turbulent flow with the SDM reduces the side of the settler and makes it more versatile, cheaper, and shallow, requiring less area than conventional technology, reducing costs, and increasing flow rates where it can operate properly. Thanks to the versatility and low cost of the technology, it can be implemented in rural cities such as Turrialba. The DWTP has a designed radial flow settler with SDM with 8 meter of diameter in the sediment chamber (see Figures 5 and 6).

Figure 5. Breña Mora PWTP - Radial flow settlers with SDM (source: LE and ESPH)

Figure 6. Full view of Breña Mora PWTP - Radial flow settlers with SDM (source: LE)

The Breña Mora DWTP has an automated system for monitoring water quality parameters that allow for precise control at real time of water supply quality with its corresponding user interfaces in the control room.

Background and context for implementing the smart water technology

The implementing process of this technology in Heredia started with a need. The Mayor of the Municipality of Santo Domingo in Heredia established communication with the developers of this technology with the goal of improving water quality in Santa Elena, an area with 5 surficial water intakes which was affected by heavy rain and runoff generation reducing water quality for a period of 4 to 6 hours (such as altered apparent color and increasing turbidity). As a response, in 2006, LE Company started gradually to improve the aqueduct system of this municipality with water intake modification to filter elements of more than 1 mm in size, and then, developing the clarifier, testing it with a pilot in Santa Elena's water treatment plant with very good results. Then, in 2018, having hear of such experiences, the ESPH also acquired the technology for some of its water treatment plants–after a tailored adjustment and further improvements of the technology meet to its particular needs.

The technology complies with national and international regulations regarding the discharge of the sludge that is separated from the water and regarding the quality of the water that is distributed. The design of the structure and materials of the tank where the SDM settler is contained was built under the American Water Works Association (AWWA) standard.

From a wider perspective, Costa Rica has a National Drinking Water Policy for the period 2017-2030, where one of the guidelines is the rational use of drinking water. It states that water supply sources must be used efficiently with appropriate infrastructure and technologies to ensure their sustainability. In addition, the 2008 National Integrated Water Resources Management Plan, still in force, has as one of its guiding principles, the promotion of efficient water use, as expressed in the more recently elaborated National Drinking Water Policy. Both the national water policy and the national integrated water resource management plan are actively being updated.

Although current policy and planning instruments in Costa Rica recognize the importance of infrastructure and appropriate technologies, this is not reflected in the facilitation or specific incentives for the development and implementation of innovative technological solutions, such as the Sediment Dynamic Multivortex-SDM, to ensure the potability of water, which is presented in this case study.

In the case of the ESPH, there is a very particular situation that makes it a recipient and pioneer in the use of this technology. It has an Integrated Management System that includes all activities and processes related to the commercialization and provision of potable water distribution services, together with the other public services they provide (electricity, wastewater treatment, and communications). Since 1999, ESPH has been a pioneer in promoting incentives for the protection of water resources. It became the first aqueduct who charged a "water tariff" for the protection of water resources. In addition, ESPH is investing in the efficiency of its water purification plants. According to the head of Potabilization Management of ESPH, the plants they have been building are an example at the national level, due to the type of technology and because of the space where the project is developed, which, unlike older technologies, occupy less area (María José Calvo, head of Potabilization Management at ESPH, personal communication).

Challenge addressed

There are three main challenges identified in this study. The first challenge is to ensure the provision of safe drinking water; the second has to do with financial issues; and the third, with capacity building.

Provision of safe drinking water

The operational part of our water security concept involves three dimensions: (1) the level of system function (i.e., supply services); (2) risks to these services; and (3) robustness of system functioning (Krueger et al, 2019), which reinforces the need to develop and implement innovative solutions for drinking water treatment plants. It is in this third dimension that the "Sediment Dynamic Multivortex (SDM)" technology provides a feasible response, particularly in a context where water sources come from surficial water prone to high sediment load produced because of extreme rainfall events.

Figure 7. Breña Mora's water catchment

Financial issues providing drinking water

A typical 250 million liter per day (MLD) no-filtration WTP (Water Treatment Plant) might cost $104 million in capital costs to build, plus $1.7 million per year in O&M (Operation & Maintenance) costs, for a total annual cost of $8.5 million. This cost is 20% lower than a so-called conventional filtration plant, which uses sand or gravel filtration. On the other hand, an advanced filtration plant, such as one using membrane filtration, would have 2.1-fold greater annualized costs than a conventional filtration plant (McDonald et al, 2016).

Although the technology proposed in our study was applied to a small city (around 12,000 people) compared with the large cities studied by McDonald, et al. (2016), we can classify our reported technology as an "hybrid" between advanced filtration if we consider the disruptive technology supporting the DWTP, and a conventional system if we consider the relative lower cost associated with this technology (600,000,000 Costa Rican colones or 970,000 USD approximately for the whole DWTP, where the SDM technology represents around 6-10% of this cost). Although this technology has a lower cost than traditional systems, it is constantly improving and adapting functionally to the user's needs. The developers have the flexibility to identify specific needs for different contexts, adjusting the equipment to the new conditions. Therefore, financial issues could be overcome when technology is individually tailored.

Capacity building

A gradual changing from centralized to fully automated operation is currently ongoing within DWTP with consequences like increase in efficiency and a better and more stable water quality. Nevertheless, such automated treatment plants require sophisticated operator care (Trussell, 2000), but could also be linked with online process optimization. Online measured water quality data would feed models that predict the development of process parameters. As a result, the treatment processes would be adjusted to prevent the violation of operational windows of water quality parameters, saving costs and emissions by reducing the use of chemicals and energy (Worm, et al, 2010). This automated operation is also part of the innovation provided by the "water smart technology" we are reporting in this case study. The system used in our case is the Supervisory Control and Data Acquisition (SCADA). One of the associated benefits of this automation is a reduction in the chlorination process, which is a treatment requested by the Costa Rican regulations (Reglamento para la calidad del Agua Potable, No 38924-S).

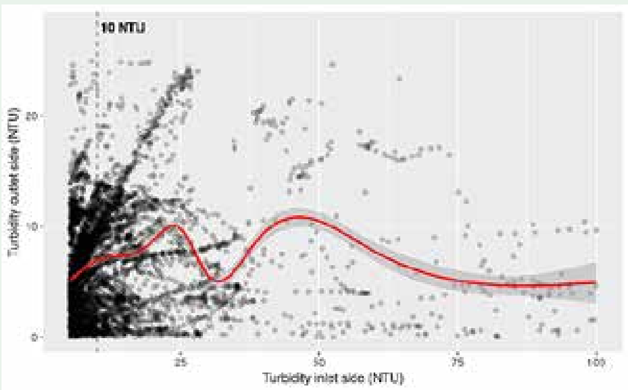
Brief exploration and data analyses for Breña Mora DWTP

We did a basic exploration data analysis (EDA) of our recently installed innovative technology. A total of 878,495 observations for the turbidity variable is reported here, given that turbidity is one of the most revealing variables to account for in the efficiency of sediment removal for this technology. The observations of turbidity were stratified into three groups: settler inlet side, settler outlet side, and final filter outlet. For all our analyses, we used R software Version 4.1.0 (R Core Team, 2020).

Covariation of turbidity between inlet to outlet side

The type of co-variation between the variables of turbidity of the settler at inlet and outlet side is not linear. This co-variation is important because it will allow to approximate the expected value of turbidity in the outlet related to values at the inlet. The spline is shown with the fitting curve–see the red line in Figure 8. Under 10 NTU turbidity settler at inlet side, the co-variation between variables looks linear even up to 25 NTU. For settler turbidity inlet side, the average estimate of % remotion of turbidity (RT) to over 10 NTU is 76.3%. The SDM's designer informed that the value of RT is the expected value according to the results in other installed systems. Nevertheless, the SDM has not been optimized yet, so the results could be improving.

Figure 8. Turbidity over 10 NTU only for inlet and outlet side from settler.



The intensity of the dot's color represents the concentration of observations (the darker the dots, the higher the concentration). It is noted that the highest concentration of observations dots is under 25 NTU inlet side and 15 NTU outlet side, approximately.

Expected performance on Turrialba city of SDM
Currently, the Municipality of Turrialba (MT) has only annual records of turbidity, with values less than 5 NTU in non-rainy events and does not have records of turbidity data on rain events; however, they have proof of sediment problems. However, according to Figure 8 and the turbidity records of "La Roncha", the expected value of outlet side for a settler with SDM technology can be close or lower to 10 NTU in rain events.

The MT report an average flow of 13.25 l/seg and minimum flow of 10.92 l/seg. Thus, and based on LE's criteria, the design of settler requires adaptation in dimensions by the location and flows. Final required adaptations can be defined in preliminary studies, commonly performed for any project.

Policy implications, recommendations, or next steps

To scale the innovative technology presented here, from big (related to Costa Rican context) to small cities, several considerations should be taken. Particularly for the municipality of Turrialba, first steps related to field visits, exchange of experience, and general diagnostics of local needs for drinking water systems are already in place. Adaptation of the technology will be the second step, also in progress based on this report, where our partner and developer of this technology is starting with simulations, numerical assessment, and optimization of the first and second version of the device (Sediment Dynamic Multivortex (SDM). The third step involves data sharing together with municipal commitments, which is also in place. Policy recommendation goes in two directions: (1) for the ESPH, which already operates the technology, we suggest the permanent update of potential water sources based in projections of urban water demand, as well as renewed efforts to work in integrated watershed management to prevent and reduce the potential sediment load affecting its DWTP. Outstanding efforts are already ongoing with ESPH collaborating in the first water fund in Costa Rica (www.aguatica.org), and previous to this initiative, the pioneering effort of the ESPH implementing a water tariff to be used in best watershed management practices is an example that currently is up scaled at a national level (Public Utilities Regulatory Authority-ARESEP by its Spanish acronym) and its tariff for the protection of water resources); (2) for the MT (Municipality of Turrialba), which is the potential recipient for the adaptation of the technology, we suggest to continue updating the baseline for the DWTP, particularly with data gathering. In addition, to prioritize and reorganize the municipal budget towards the inclusion of this adapted technology and to analyze globally the opportunities and projections of urban water demand to improve, increase, and redesign its DWTP. Finally, the MT should also consider implementing schemes of water tariff or similar mechanisms to obtain resources for integrated watershed management to prevent sediment load and contamination as well, which overall, for both ESPH and MT will represent a reduction in water treatment to guarantee the water security under a Smart Water Cities approach.

It is important to notice the non-technical elements which facilitate implementation of this technology. One such aspects is the capacity of the "innovator"–in this case, Lucas Electrohidraulica–to constantly improve and adapt their technologies using the data produced by previous developments (drinking water treatment plants) as an input for this continuous process of innovative development. Another aspect is the flexibility, which is a key value to overcoming limiting factors like financial issues, again, adapting the technology to the financial capacities of the users, and the constant ability for observation, investigation, and overall, innovation with their own effort to invest with the goal to cover the necessity of drinking water operators to achieve sustainable standards of water quality for water security. A third important aspect is the local conscience on the importance of the integrated water resource management present in both ESPH and the Municipality of Turrialba. This characteristic of local stakeholders set the bases for innovation and allocation of resources to implement promising technologies to move towards Smart Water Cities.

Acknowledgements

Our deep acknowledgement to the Enterprise of Public Services of Heredia (ESPH) for the support in sharing its data and for its practical experience, to Pablo Gonzales Lucas and Gustavo Tellez by Lucas Electrohidrahulica for data sharing and technical guidance, and to the Municipalidad of Turrialba for data sharing, and altogether for their interest and commitment with smart cities initiatives.

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Hong Kong (China)

Smart technologies, actionable data, and domestic water consumption in Hong Kong: Potentials and constraints

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Abstract
With the domestic sector becoming the dominant user of water in many global cities since the turn of the millennium, water planners have accordingly shifted their attention to households in strategizing long-term water conservation projects. Smart technologies, at the same time, have made progress in leaps and bounds. Emerging technologies have enabled the HKU Water Centre to build a Smart Water Auditing system which makes use of a set of judiciously selected and integrated technologies to build an IoT-based Smart Meter Analyser to collect, analyse, and communicate to ordinary people through an easy-to-read visual format, some real-time, ultra-fine-grained actionable data to induce them to embrace habit-changing, positive water conservation behaviour. In addition, the Smart Meter Analyser shows the potential to help transform, at low cost, a city's conventional mechanical water meters into fully functional smart meters that could transmit high-resolution digitized water consumption data to a cloud-base processing center for policy analysis. The major hurdles that might block the way towards making use of such actionable data to suppress domestic water consumption would stem mostly from the usual institutional constraints, including political ineptness, bureaucratic inertia, and resistance to adopting innovations that are inherently disruptive to established practices.

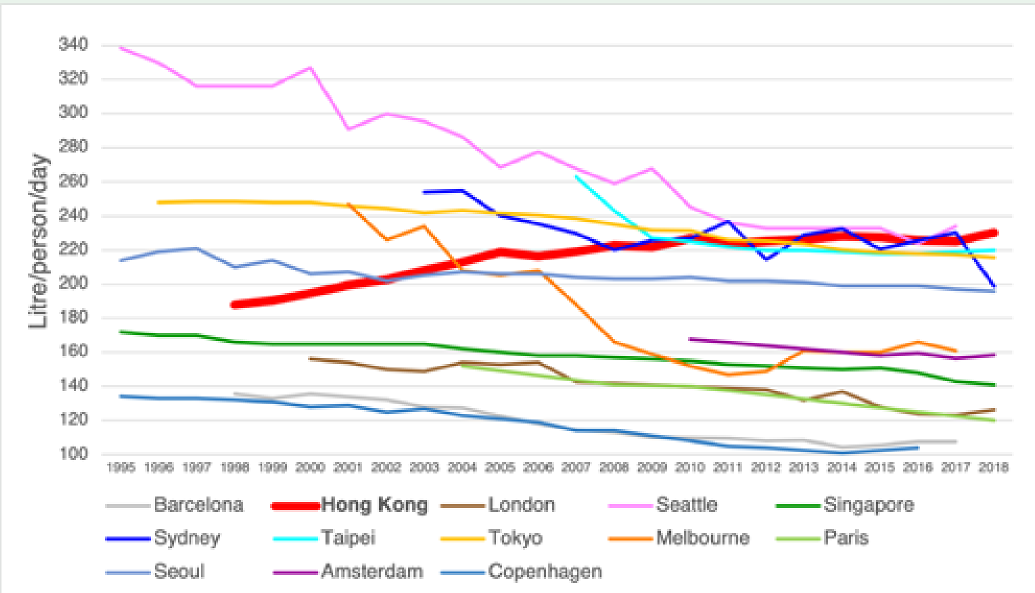
Introduction
An inherently water resources-short city, Hong Kong's water agency nevertheless has been able to provide a 24/7/365 water supply since the early 1980s—resulting, paradoxically, in a perception of water abundance among the populace. This un-interrupted municipal service, spanning four decades, is made possible by a combination of factors, both institutional and structural. A conventional, inter-basin transfer engineering scheme brings surface water from the East River, a tributary of the Pearl River, through an 83-km aqueduct, into the Special Administrative Region (SAR) since the 1960s (Lee & Moss, 2014). This water infrastructure was the product of a 1960s-era political negotiation between London and Beijing, at the former's behest, albeit reluctantly (Lee, 2013). Since the turn of the millennium, both the quality and quantity of this imported water have been guaranteed by formal agreements signed between the Guangdong provincial government (the seller) and the Hong Kong SAR government (the buyer). Triannual negotiations between these two parties, conducted since the noughts, determine the quantity and the price of this imported water. One unexpected, but highly consequential outcome of these tacitly contentious negotiations is an over-supply of East River's water for Hong Kong.

Compounding the repercussions of an over-provision of imported water on Hong Kong people's water psyche is the deleterious effect of an egregiously under-priced tap-water. Water tariff levels have been frozen since 1995-96, a by-product of political impasse of those times that have remained unresolved today (Lee & Nickum, 2015). Nowadays, household water bills, on average, recover only 37.8 percent of the actual unit production cost of water, according to a recent study (Zhao, et al., 2019). Consequently, pricing, a tool commonly used in other jurisdictions to induce water conservation behaviour, is a blunted policy instrument in Hong Kong. In addition, the magnitude of over-supply has been exacerbated by a drastic drop in overall demand, caused principally by deindustrialization that started around the late 1980s. The drop in industrial demand also means that the domestic sector now accounts for more than half of the city's total demand. Domestic water consumption thus has begun to draw water managers' attention when they formulate the latest batch of water conservation measures.

Amidst all these changes in the water economy, the Hong Kong government has signed onto the global sustainability agenda, if belatedly (Sustainable Development Unit, 2005). This commitment has slowly found its way into the water sector, resulting in a recently promulgated pledge to reduce overall per capita water consumption by 10 percent by 2030, referencing 2016 as the base year to combat climate change (The Hong Kong SAR Government, 2017). With the city's overall demand stabilising and perhaps plateauing soon, concerned decision-makers must have vetted such a modest target and concluded that it is technically achievable. One statistic, however, has stood out as a cause for concern for policymakers because it has defied a global trend and has not shown any signs of reversing itself any time soon.

As shown in Figure 1, while cities around the world have registered a steady, if gradual, decline in per capita domestic water consumption level over the course of the past twenty-plus years, Hong Kong has wandered into the opposite direction. The continuous upward drift in per capita domestic water use, if unchecked, could jeopardize, if not derail, the policy agenda on water conservation. The question of how to tame and trim domestic water consumption has therefore taken on a certain degree of policy imperative. This shift of focus onto domestic water consumption to driving the overall policy agenda of water conservation has provided the impetus for this policy-oriented research project.

Figure 1. Per capita domestic water consumption in Hong Kong and selected cities



The formulation of an effective water conservation strategy and an evaluation of its efficacy after it has been implemented is predicated on an accurate, complete, and nuanced understanding of how much water people are using, when they use it, and for what purposes at home. Such information, however, has never been collected in Hong Kong. That is, water planners have been doing their job with only a partial picture of domestic water consumption. They have been deprived of a nuanced understanding of household-level water use because they did not have the tools to collect requisite data that could be disaggregated into end-use types at that micro scale. Past attempts to measure the percentage distribution of domestic water consumption by end-use types have been faulted for producing unreliable results because the reported figures were subject to the vagaries of study participants' self-reporting skills.

The per capita domestic water consumption figures for Hong Kong, as shown in Figure 1, contain two components: potable water and water for toilet flushing. The reported figures for the former are fairly accurate because potable water supplied to almost all the households is metered. However, the fact that 85 percent of the households are using seawater for toilet flushing (with the other 15 percent using freshwater) complicates the picture for meaningful cross-city comparison purposes. This is because the published statistics on seawater provision do not differentiate between the domestic and the non-domestic.

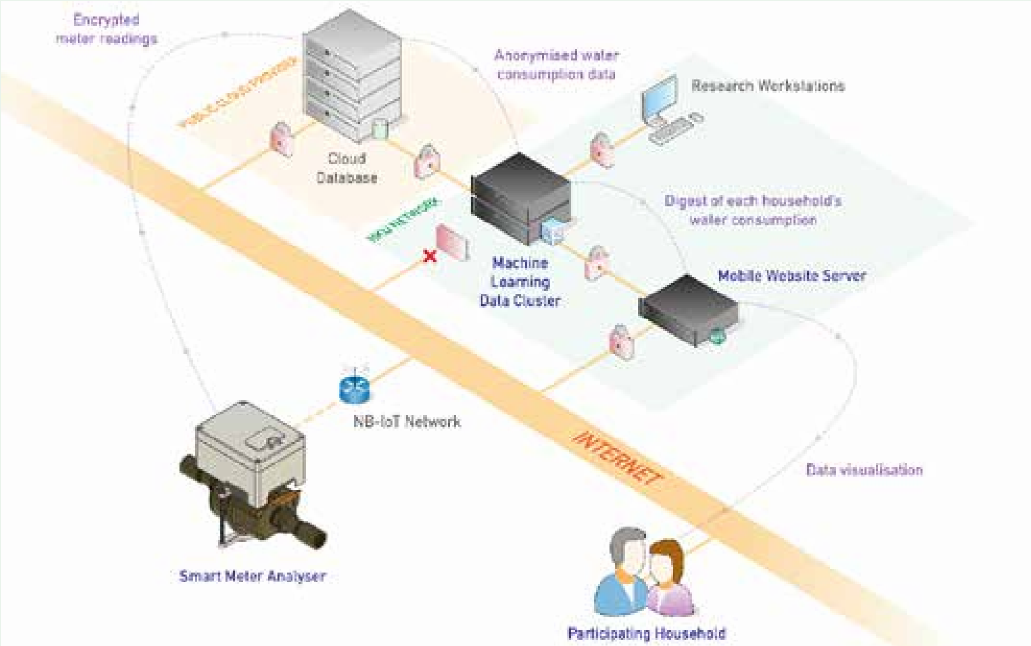
To fill the above-identified knowledge gaps, the project's research design is purposefully formulated to integrate a select set of Internet-of-Things (IoT)-based smart technologies—comprising Big Data, AI, and Machine Learning—to create a Smart Water Auditing (SWA) system to collect, analyze, and report ultra-high resolution data on domestic water consumption. The SWA system will enable us to (i) produce an accurate, complete, and nuanced depiction of how, when, and how much, water is being used at home; and (ii) design, test, and evaluate the efficacy of a near-real-time feedback mechanism to induce and instil water conservation habits on the users of the system. In a nutshell, our team has assembled a judiciously selected set of smart technologies to enable us to produce actionable data, easily visualised on a mobile device, that will impact domestic water consumption behaviour.

Creating a Smart Water Auditing system

The Smart Water Auditing system is comprised of three major components:

- A self-built, non-intrusive clamp-on Artificial Intelligence analyzer module, which we can affix onto a conventional mechanical water meter within minutes and transform the latter into a water meter capable of performing smart functions;
- Machine Learning algorithms, such as support-vector machines and artificial neural networks which could disaggregate total household water consumption data into specific end-uses: showering, washing machine, kitchen-tap, and basin-tap; and
- A mobile website through which users could login to view the break-down, by end-use type of their day-to-day water consumption data.

Figure 2. A Schematic Illustration of the Smart Water Auditing system



The SWA system is an output of a five-year research project initiated by the HKU Water Centre, with seed-funding provided by the Water Supplies Department (WSD) of the Hong Kong SAR Government. Begun in late 2019, the project team has developed an IoT-based Tap Sensor for collecting tap-based water consumption data to train a Machine Learning model to disaggregate water end-uses. A scalable data collection architecture was created to collect tap-based consumption data from 21 households in Hong Kong since early 2021. As of today, over two hundred thousand annotated end-use-activity profiles have been captured by Tap Sensors with data resolution set at a 1-second interval, coupled with a 2ml accuracy level. This first-of-its-kind tap-based data collection exercise will provide indispensable ground-truth information for the Smart Water Auditing project as well as the global research community working on this topic because this set of original, annotated data will help improve the accuracy and the generalizability of residential water end-use classification models significantly (Gourmelon et al., 2021). The team has also modified the engineering design of the Smart Tap Sensor and turned it into the First-Generation Smart Meter that is capable of recording per-second household-level water consumption data. The data resolution specifications of the Smart Meter, set at a 1-second interval, have proven to be sufficient for meeting the data requirements for the disaggregation of end-uses by Machine Learning algorithms.

The First-Generation Smart Meter, nevertheless, has a major weakness: The in-line installation of such a Smart Meter involves plumbing works and, hence, temporary suspension of water supply for an entire apartment—resulting in nuisances for water customers and incurring prohibitively expensive project costs. Subsequently, the HKU Water Centre decided to bypass these operational difficulties and developed a Second-Generation Smart Meter, which is a non-invasive, portable AI analyzer module. We call it the Smart Meter Analyzer (SMAN) (see Figure 3).

Figure 3. A Smart Tap Sensor (top-left); an in-line Smart Meter (top-right); and a Smart Meter Analyzer prototype (bottom)

The Second-Generation clamp-on Smart Meter, SMAN, leverages on the city's mature metering program (more than 99 percent of water customers are metered). By incorporating the most recent advances made in edge computing, computer vision, and networking technologies, SMAN can adapt to any WSD-issued mechanical water meter and turn it into a smart meter. Ultra-high resolution water consumption profiles (100 ml, at 5-second interval) could be constructed via SMAN. The Project Team plans to test and roll out a fully functional SMAN module to collect fine-grained water consumption data from 300 randomly selected households from 2022-2024. These water consumption profiles, with time sampling resolutions comparable to those of international best practices, will be classified and disaggregated into specific end-uses by a Machine Learning model. Narrow-band IoT (NB-IoT), a form of Low-Power Wide-Area Network (LPWAN) technology, is used to transmit encrypted digitized water meter readings from a range of urban settings in Hong Kong—including tightly packed high-rise buildings in densely populated districts as well as remote sites that are poorly covered by conventional telecommunication infrastructures—to the Project's secure cloud server. Data are then disaggregated into categorized water end-use information.

While a team of engineers are building the hardware and the software components of the Smart Water Auditing system, a team of social scientists have merged a constellation of pertinent social science concepts—such as the notion of environmental ethics, as well as ideas on behavioural and cognitive psychology that are embedded in feedback intervention theory and goal-setting theory—into constructing an intuitively enticing feedback platform of the SWA system. Users, through this platform, will be able to view real-time detailed information on how much, and how, water has been used at home via their mobile devices (see Figure 4). The bedrock premise of this feedback platform: real-time feedback on water consumption could serve as a powerful nudging tool to help responsible users of the Smart Water Auditing system by empowering them to experiment with and embrace habit-changing water conservation practices. Users can benchmark their own water consumption level with the study's overall averages, for instance. More importantly, users can set their own water conservation targets and measure the progress they are making towards achieving those targets. The platform will also push notifications on practical water-saving tips that are customized to fit with each user's unique water consumption profile.

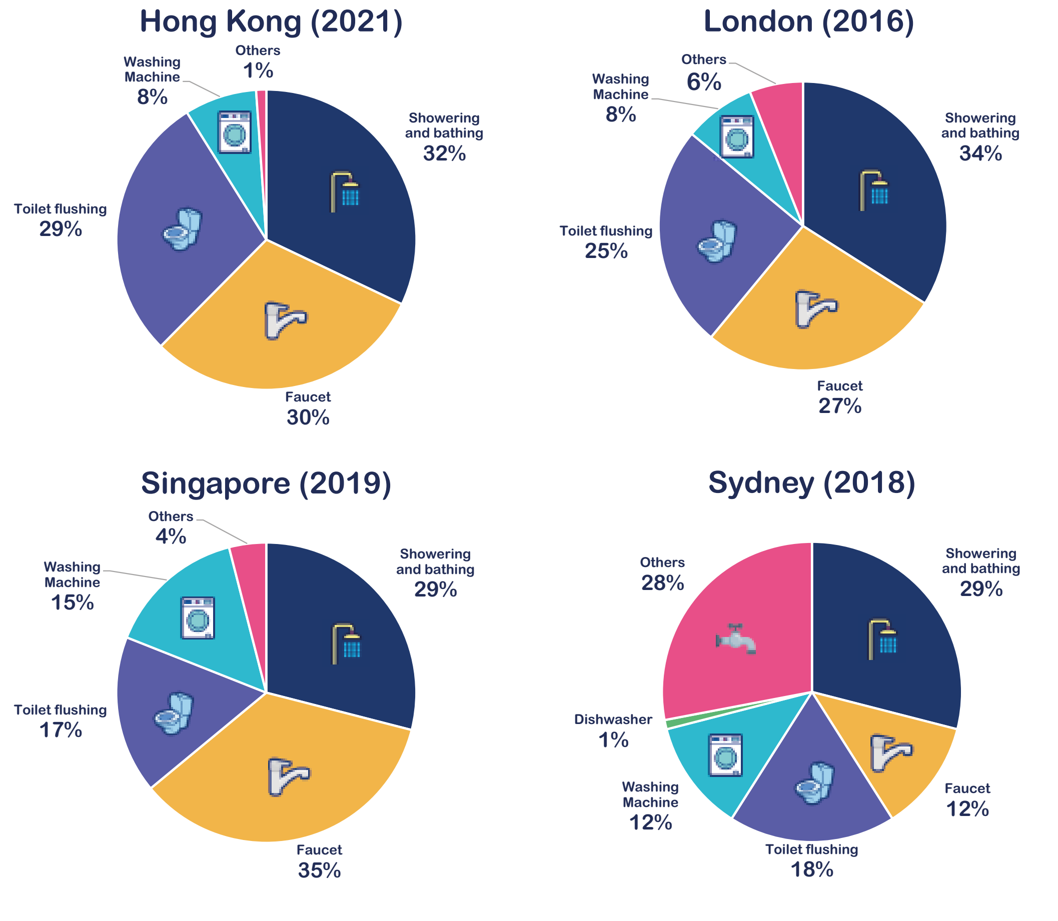
Figure 4. A mobile website for providing feedback on water use to the users

Potentials of and constraints to the Smart Water Auditing system

In other parts of the world, water utilities have conducted smart water metering projects to collect data to help them monitor water losses, forecast water demand, explore water restriction policies at times of water supply interruptions, and formulate demand management strategies to identify and reduce peak demands (Di Mauro et al., 2020; Pesantez et al., 2020; Rahim et al., 2020; Ramos et al., 2019). While these researchers have made use of smart technologies to generate and report near-real-time data on domestic water consumption, the HKU Water Centre is the first to collect empirically gathered ground-truth data, at 1-second interval, in multiple households continuously for up to three months for the training of generalizable Machine Learning models.

The Smart Water Auditing project, by producing actionable data to induce positive behaviour on domestic water conservation, aptly demonstrates that recent technological advancements have enlarged the boundary of policy imaginations by allowing researchers and policymakers to conduct analysis at unprecedentedly granular levels. In converging IoT, AI and data analytics in this project, we have begun to produce the first set of policy-centred actionable data for Hong Kong on household-level water consumption. Water utilities could make use of such data to formulate, calibrate, and evaluate household-level water conservation measures to reach city-level water conservation goals. The early findings of the SWA project are shown in Figure 5, juxtaposing Hong Kong's data—which are the first-of-its-kind ever empirically derived for the city, with those of Singapore.

Figure 5. Domestic water end-use distribution in Hong Kong (2021), London (2016), Singapore (2019), and Sydney (2018)



Moreover, the Smart Water Auditing system has shown its potential to help expedite the digitization of a city's urban water management system in a cost-effective manner. For instance, in Hong Kong, WSD has installed over three million mechanical water meters, which are single-purpose devices (for billing) that measure the quantity of water consumption of tap-water customers over a 4-month billing cycle. The financial costs and technical difficulties in retrofitting the conduit system in old buildings to accommodate the cabling network of AMR outstations are the major hurdles that stand in the way of the implementation of a city-wide AMR scheme. Subsequently, tap-water customers residing in these buildings could not enjoy AMR's beneficial features, such as alarms on leakage and timely notifications on over-consumption.

The almost universal metering coverage achieved in Hong Kong, nonetheless, has set the stage for the city to easily transform its domestic water supply network into a digitised, smart system. The clamp-on SMAN could serve as a low-cost alternative to commercial smart meters that require costly in-line installation. The minimal efforts required to install a SMAN module means that it could be rolled out rapidly to digitize and modernize a city's water metering system. Coupled with the application of related, emerging smart technologies, it is now plausible for Hong Kong's long-term water planning exercise to transition to a truly real-time, data-driven, evidence-based policy-making process.

In the first two years of the project, the Project Team has spent much time trying to resolve technical issues that are commonly encountered in the early stages of any practice-oriented research projects. In our case, one salient technical challenge pertained to optimizing the power requirements of several types of emerging IoT technologies, each with its own specifications, when we integrated them to create a new device. We have learnt that such technical hiccups, with engineers' usual traits of persistence, ingenuity, and patience, are surmountable—given time and sustained financial support.

On reflection, we surmise that the major constraints that might block the realization of our vision of the production of actionable data to facilitate domestic water conservation in Hong Kong stem primarily from institutions. First, for a real-time, data-driven, water conservation-centred feedback mechanism to work on targeted users, the charging principles that have underpinned the city's water tariff regime since the early 1980s will need to be restored and strenuously enforced. That is, at a minimum, customers will need to pay for the full cost of water production and provision. Otherwise, both the knowledge effect and the nudge effect of the feedback platform will be heavily discounted, if not totally discarded.

Secondly, instead of soft targets, the Water Supplies Department should be assigned hard targets and given a chance to demonstrate its resolve, commitment, and professionalism. Up until the current moment, water conservation campaigns conducted under the aegis of WSD do not include any targets. For instance, the 'Let's Save 10L Water' campaign, launched in 2014, did not come with a target attainment date. Inevitably, over time, viewed from the public's perspective, these words were equated with a sloganeering project, and no discernible outcome could be attributed to its implementation.

Thirdly, to align itself fully with the conservation-inspired zeitgeist of the global water community, Hong Kong's water agency will need to re-define its remit to embrace a broadened agenda that goes beyond its singular objective of achieving a 99.9% reliability in provisioning water supply for its customers. Instead of such a narrow focus, WSD should aim at pursuing a larger set of KPIs that bind its functions and operations and to fulfilling some larger, and admittedly challenging, but rewarding, societal aspirations such as decarbonization and ultimately, net zero carbon. Such a structural, and fundamental, shift in agency priorities is, of course, a tall order for any government in any parts of the world that are deeply entrenched in decades-old mind-set. The impetus to reforming outdated practices could only emanate from the city's top echelon of decision-makers, whose attention has, unfortunately, been distracted by a string of more immediate and contentious political and social urgencies in recent times.

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6.

Mumbai (India)

Metering Mumbai: Lessons from AMR technology use in Mumbai's water supply network

Sharlene L. Gomes

Mumbai (India)

Abstract

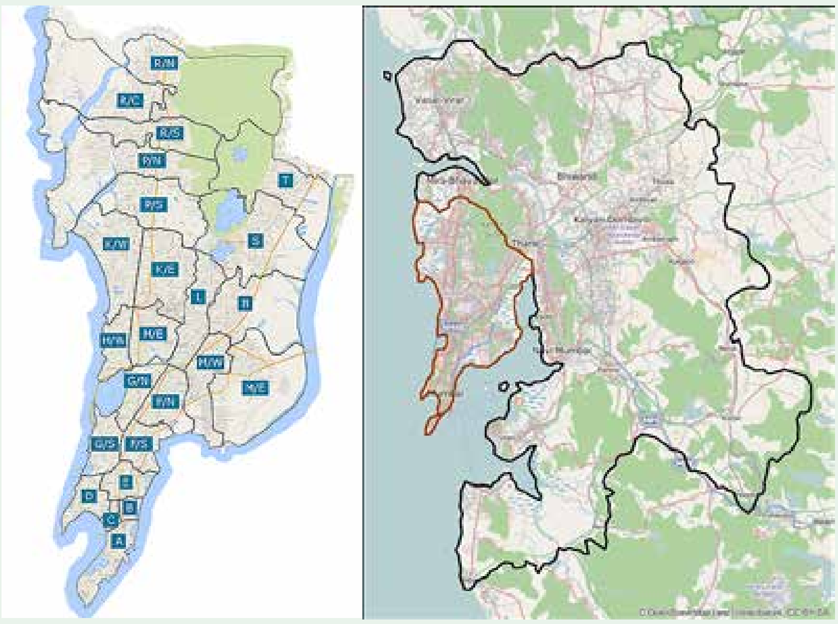
Mumbai city (India) faces an immense challenge of managing water supply needs to it's over 18 million consumers. In 2009, the municipality initiated a pilot application of Automated Meter Reading (AMR) technology to improve revenue collection and in the long-term demand management. At the time, most of Mumbai's water meters were non-functional, affecting cost recovering and water management. This chapter examines the pilot phase of the city's AMR project. Comparison of consumption data pre and post AMR illustrate the improvements in billing accuracy. However, public opposition, financial, physical, and technical constraints were faced during the project. This early example of smart water technology in India is further discussed in relation to more recent policy developments, such as India's smart cities mission. This chapter explains why the lessons from Mumbai are still relevant today and highlights the need for simultaneous investments in institutional capacity to realize the full potential of smart water technologies.

Overview of Mumbai City

Mumbai, capital of Maharashtra, is the seventh largest megacity in the world (United Nations, Department, 2018). It has a tropical, wet and dry climate with a distinct monsoon season (June to September) during which it receives heavy rainfall and can experience major flooding events.

Historically, Mumbai consisted of separate islands connected through land reclamation projects. Over time, Mumbai city expanded to the northern suburban areas to form the peninsula area of Greater Mumbai (437.71 sq km) (MCGM & EMI, 2011). Today, Greater Mumbai comprises of three regions: the island city, the eastern, and the western suburban areas (Z´erah, 2009) (see Figure 1).

Figure 1. Administrative wards in Greater Mumbai (L), Map of Greater Mumbai & Mumbai Metropolitan Region. (Source: Disaster Management Department, 2017; Chakraborty et al., 2015)



Between 1991-2002, Mumbai's population grew by 28%, especially in the eastern and western suburbs. Urban expansion also gave rise to satellite cities which together comprises the Mumbai Metropolitan region (Hust & Mann, 2005; Z´erah, 2009) (see Figure 1). Today, Mumbai's population is estimated to be 21 million and is projected to become the 4th most populous city globally by 2030 with 29 million people (Department of Economic & Social Affairs, Population Division, 2015; HT Correspondent, UN, 2014). Lack of affordable housing and high real estate prices in Mumbai force residents who cannot afford formal housing to live in slums. Estimates of Mumbai's slum population is between 41% and 55% of the total population (Desai, 2014).

Water Supply in Mumbai

The Municipal Corporation of Greater Mumbai (MCGM), established in 1882, is the public authority responsible for urban services including water supply. Its functions and operations are based on the Mumbai Municipal Corporation Act (1888).

The organizational structure of the municipality consists of a deliberative and administrative wing. The deliberative wing is headed by the mayor and includes the standing committee comprised of elected municipal councilors (BMC, 2019a). The city is divided into 24 administrative wards, each governed by an assistant commissioner or ward officer. Water supply services are managed by the hydraulic engineering department (BMC, 2016b). At the ward level, this department is responsible for day-to-day functions, including water supply, maintenance, metering, revenue collection, and customer complaints.

Water supply is sourced from several rain-fed reservoirs, some within city limits, others over 100km away. A gravity-based system transports water to Mumbai via nearly 4,000km of pipelines (BMC, 2016b; Desai, 2014). Groundwater from 3,950 dug wells and 2,514 bore wells serves as a supplementary source for all other purposes besides drinking and domestic uses (Gupta, 2013).

A majority of the MCGM's water users are domestic. Water supply provisions for domestic users differ for residents living in apartments, private dwellings, or in slums. For apartment and private dwellers, it ranges between 240-250 litres/ per capita per day. Meanwhile, slum residents receive stand post connections (Desai, 2014). Some residents live informally on pavements, under bridges, near railway tracks, etc. They represent the most marginalized population, are excluded from municipal supply, and are forced to beg for water from other areas or through illegal connections (Bapat & Agarwal, 2003).

Currently (as of 2021), Mumbai receives 3,850 million litres per day (MLD) although water demand is estimated at 4,200 MLD. Demand is furthermore projected to reach 6,000 MLD by 2041 (CDEM, n.d.). Therefore, in order to meet the current and projected future water demand, a series of additional water supply projects, infrastructure improvements, such as refurbishing old infrastructure, water auditing, and construction new underground tunnels is underway (Gupta, 2013; Pardeshi, 2020; Purohit, 2012). A 200MLD desalination plant is also envisioned in the near future (Cheif Engineer, 2021; Upadhyay, 2020)

Water management issues in Mumbai

When smart water technology was first considered in Mumbai back in 2005, it faced a number of challenges. There was a water supply deficit of approximately 850MLD (Itron SmartMedia, 2011). As a consequence, water supply was intermittent, ranging from two to four hours per day to 24 hours in some zones (Desai, 2014; MCGM, n.d.-c). The city's ageing water supply infrastructure was also in dire need of refurbishment. Mumbai regularly faced incidents of leakages, pipe bursts, and water losses upwards of 20% (Desai, 2012; Desai & Raj, 2012; Nallathiga, 2006). Thus, there was a need to reduce network losses to meet future demand.

Water meters allow for revenue generation of both water supply and sewerage. At the time, accurate estimations of water consumption were constrained by a lack of metering capacity. The city had approximately 300,000 water meters. The policy was to charge users based on a metered supply, yet 50% of domestic meters and 20% of bulk meters were damaged or non-functional (Desai, 2012).

Figure 2. Examples of meter reading issues (clockwise from top left): Meter buried under footpath, enclosed in cement, broken meter, readings not accessible (Gomes, 2012; Itron India, 2009)

Furthermore, users were charge based on average (rather than on actual consumption) and water bills were not generated in time, resulting in outstanding dues of approximately $70 million (INR 525 crores) (Sharma, 2011). Part of the billing problem was due to manual meter readings. Mechanical water meters were used to generate consumer bills. The increase in mechanical meters due to population growth, high housing density, poor meter installation, and water logging in the monsoons made meter reading extremely challenging (see Figure 2). Manual readings require manpower and runs the risk of human error or meter tampering.

The metering problem also made it difficult for the MCGM to allocate water supply between the city and suburban areas. A study shows how south Mumbai (city area) was receiving the highest per capita water supply despite having the lowest population, leaving the more populated suburban areas with less water (Desai & Raj, 2012). Thus, there was a pressing need to replace non-functional meters and improve the efficiency of meter reading.

Automated meter reading technology

Automated Meter Reading (AMR) is a type of smart water technology. They allow for remote collection of meter readings through radio frequencies, removing the need for physically accessing meters. AMR technology offers a range of benefits for water utilities including:

- Faster, more frequent meter readings to calculate changing consumption patterns.
- Leakage and water theft detection helps reduce non-revenue water.
- Improved billing accuracy.
- Awareness of resource use. In Ann Arbor, Michigan, users track consumption in real-time and calculate which activities can help lower consumption.
- Two-way (remote) meter management if meter readings are transmitted to a smart grid. (source: Hope et al., 2011; McCormick & Welser, 2009; Quraishi & Siegert, 2011)

AMR project in Mumbai [1]

In 2005, the MCGM initiated its AMR technology project. Mumbai was the first Indian city to invest in AMR at the time, although Delhi, Navi Mumbai, Pune, Hyderabad etc., were also conducting similar AMR projects. The municipality financed 100% of the project[2] and used a public-private partnership model.

AMR devices from three-meter manufacturers (Itron, Arad, and Chetas) were purchased and tested as per recommendations of a technical evaluation committee. Three contractors were hired in September 2008 to supply, install, read, and maintain meters. An eight-month feasibility pilot study began in 2009, where approximately 6,082 mechanical meters were upgraded to AMR (see Figure 3).

Figure 3. Installed AMR meters in Mumbai (Gomes, 2012)

Quarterly readings were taken using handheld devices and submitted to the MCGM (see Figure 4). Up to 8 meters could be read simultaneously, eliminating the need for physically accessing meters unless a problem was detected. Readings identified tampered, broken, and poorly installed meters. Tests to verify reading accuracy and investigate meter display errors, group readings, and 180-day readings were also conducted. The pilot study highlighted technical differences between the three types of AMR devices. AMR meters transmitted readings to the devices through radio frequency. The location of the meter could also be recorded on the device using GPS.

1. Information in this section is based on interviews and analysis in 2012 by the author. For more details, refer to Chapter 3,4, and 5 in (Gomes, 2012).
2. Total project cost was budgeted as $107 million (INR800 crore), however, incurred costs were $34 million (INR257 crore) as of 2012 (Controller and Auditor General of India, 2013)

Figure 4. System Architecture: Software with data transfer to billing department (L); Meter reading device (M); water meter with radio module (R) (Itron India, 2009).

A work order for 129,000 AMR meters was issued in August 2009. Installation in the full-scale phase began in July 2010, following meter modifications, performance, life testing, and site clearances from local wards. Initially, 300,000 AMR devices were ordered in this phase, but it was later scaled back to 129,744 meters. Contracts specified 1-2 years for AMR installation depending on the location and an additional 5 years for reading and maintenance.

Table 1. Overview of AMR project

Location	Pilot Study (No. of AMR meters)	Full-scale project (No. of AMR meters)
City	2,053	20,383
Western Suburbs	2,022	65,754
Eastern Suburbs	2,007	43,607
Total (No.)	6,082	129,744

Evaluation of Mumbai's AMR technology pilot project

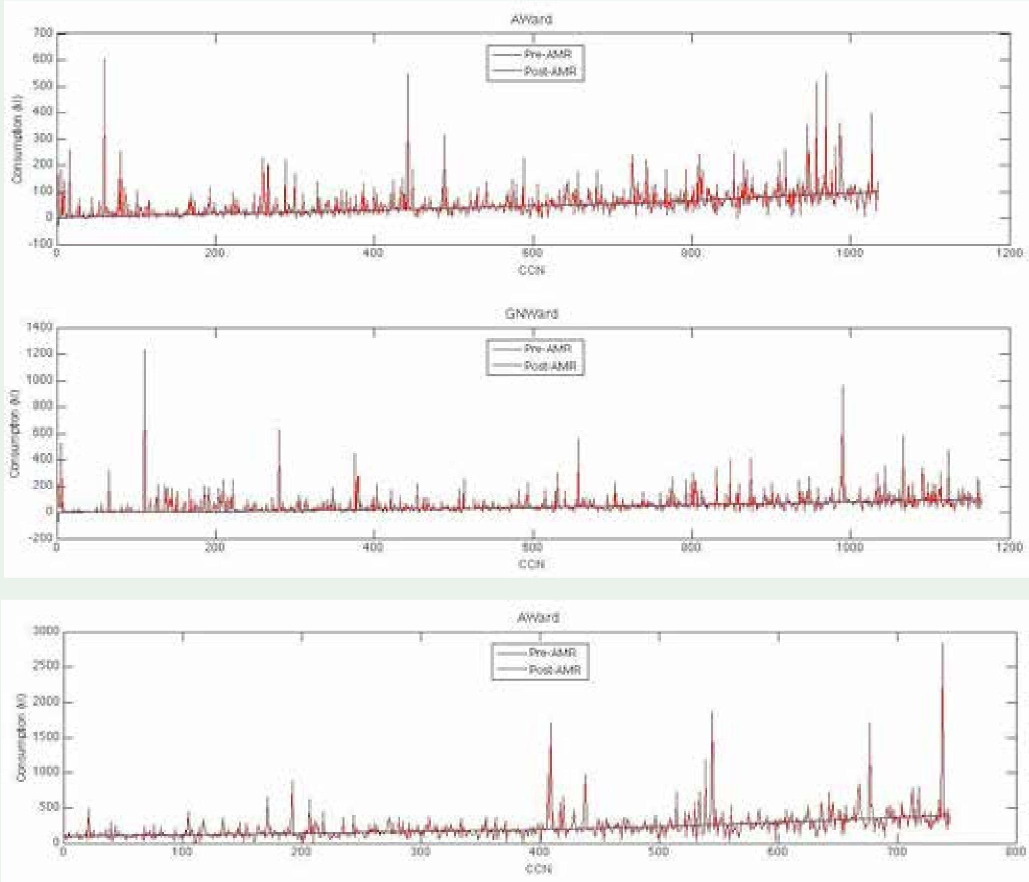
Project objectives

In the short term, the AMR project was expected to improve billing accuracy and customer transparency, improve meter reading, earlier detection of meter tampering, and help achieve universal metering and 100% volumetric billing. Long term, it would help with demand management, awareness of water use, equitable water distribution, billing lifecycle reforms, and water audits.

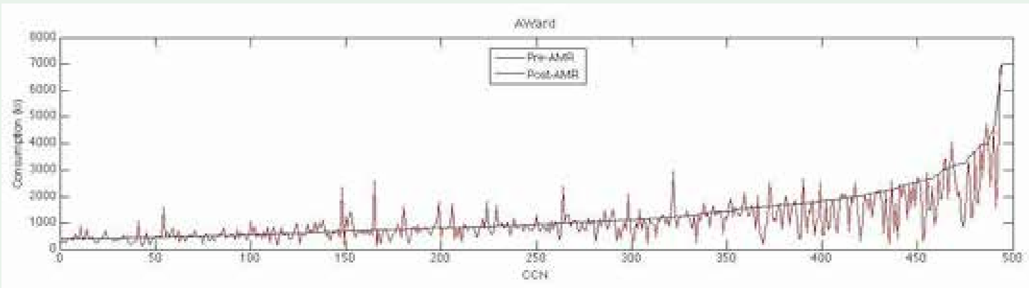
Impact of AMR on billing accuracy

Water consumption data of users from two municipal wards (A, GN) in Mumbai were compared pre- and post- AMR installation as part of a study conducted in 2012 by the author. A statistically significant difference ($p<0.05$) post-AMR installation was found in low consumption users (0-100kilo litres) in both wards A ($n=1036$) and GN ($n=1164$) (see Figure 5). For low consumption users, AMR technology improved billing accuracy. The change in average consumption pre- and post- AMR is quantified as 30% and 47% in wards A and GN respectively. Similar statistically significant results are also observed post-AMR in the 100-400kl range in ward A ($n=743$).

Figure 5. Pre- and post- AMR comparison in 0-100kl range in wards A (Top) and GN (Middle); 100-400kl range in ward A (Bottom) (Gomes, 2012).

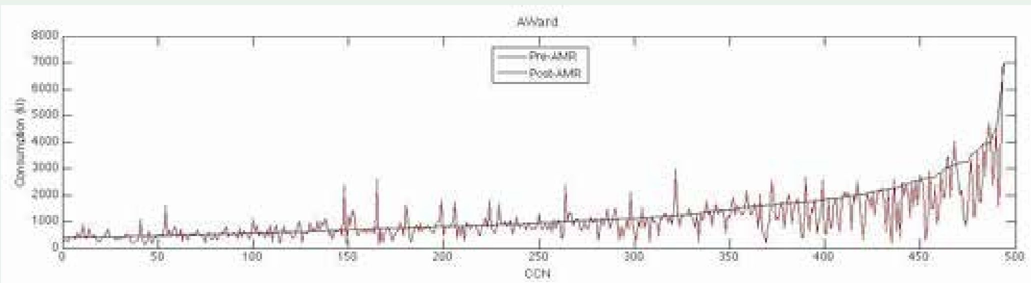


Comparison of consumption data in the highest consumption range (>400kl), shows a statistically significant result in ward A (n=495) (see Figure 6).



Here, consumption values decreased post-AMR, suggesting that consumers were over-charged pre-AMR. It was discovered that bills of some commercial users were two to five times more post AMR, revealing the inaccuracies of average billing. Results in GN ward in the 100-400kL and >400kl range were not statistically significant.

Figure 6. Pre and post AMR comparison in ward A for >400kl range



Cost barriers

The high cost of AMR meters made it a financially unsustainable for the MCGM. Typically, the cost of new meters is recovered from the consumer via a meter rent charge, which was $0.20/month (INR15) in 2012. AMR meters would increase the meter rent charge to $2.68/month (INR200) and is expected to receive public opposition. This partly shaped the decision to replace the rest of Mumbai's meters with new mechanical meters.

Implementation challenges

One of the main causes for project delays was the discrepancies in consumer data from the wards. Records of meter size and ownership, meter numbers, water connections, and consumer addresses were found to be incorrect during installation which slowed down the process. As many as 40-50 data discrepancies were identified in certain wards. There were also physical hurdles in locating meter sites and identifying connections.

Some areas also reported stolen or tampered AMR meters. Copper and other materials is typically sold from stolen meters by thefts. In response, the municipality decided against installing costly AMR technology near slums, installed tamper proof safety covers, and began charging consumers $16 (INR 1,200) to replace tampered meters (Mahamulkar, 2011; Mhaske, 2010).

Contractors were expected to submit meter readings as per the MCGM's billing cycles. However, readings were not submitted on time, thus causing delays in the generation of water bills to consumers. In some cases, this was due to inadequate training of staff, hardware, and software issues in local wards.

Public response to AMR technology

The project also faced public opposition during installation over fears of increasing water bills (Shukla, 2010). Yet, as this analysis shows, domestic users could be paying less after AMR, as bills appeared to overestimate water consumption. A higher number of complaints were also reported after AMR, with users requesting refunds for overestimated water bills.

The sharing of information between service providers and customers could also be improved. Prior to AMR installation, the MCGM issued a notice to users which did not mention specifics about the project, AMR technology, or potential long-term benefits for the consumer, such as, billing accuracy, for example.

Lessons from Mumbai's AMR technology pilot project

The primary objective for using AMR was to achieve 100% metering in Mumbai as well as achieve volumetric, accurate billing of consumers. This basic functionality of AMR (i.e. automated readings using hand held devices) appeared to improve billing accuracy in some wards.

However, the project's success was limited. A 2012 audit revealed that only 82,857 meters had been installed with 46,918 meters lying unused. Given the delays in supply and installation of the meters, the initial goal to install 300,000 meters was revised (Controller and Auditor General of India, 2013).

Despite this study's findings in billing accuracy after AMR, it appears that approximately 44% of water bills in Mumbai continue to be estimated due to non-functional meters (Express News Service, 2018). A follow-up study of AMR maintenance since installation could help identify whether current billing issues stem from the installed AMR meters or pre-existing mechanical meters.

AMR was expected to make meter readings more efficient and minimize human error and manual tampering, thus improving transparency and accountability towards the consumer. However, audits of meter readings in nine wards found that 30% of reading were recoded as 'non-acceptable'. (Controller and Auditor General of India, 2013). Further research is needed to examine underlying causes. Moreover, heavy rainfall and lightening also affected readings. Thus, if manual meter reading in monsoons is one of the concerns, then AMR does not appear to resolve this problem.

This case study highlights the value of pilot applications of smart water technology. In Mumbai, it uncovered new technical, social, financial, and institutional issues. This suggests a need for attention to other governance related aspects in addition to technology. Service providers must be able to adapt the technology to their context. For example, the MCGM could have explored several options to address the issue of cost recovery of AMR meters. Further analysis of consumption data for example, might indicate which user groups are cost effective candidates for AMR technology. However, analyzing consumer data in this way is associated with privacy concerns and thus, could not be included in the study. Alternatively, the MCGM could have sourced designs for a locally made, more economical option. This will help make technological investments financially viable in the long-term.

In Mumbai, public participation during the project could have helped generate support for AMR and its associated costs. Better communication might help consumers realize the added, long-term benefits of AMR in identifying leaks, creating water demand maps etc. which ultimately improves water supply services for the consumer. However, public acceptance of smart water technologies is difficult without access to information. Local councillors interviewed during the study were in favor of improving citizen awareness on water related projects through the media, public banners, etc. Many smart meter technologies are also accessible to citizens through apps or websites. In Valencia, for example, access to water consumption data was found to positively impact water conservation behaviour (Cominola et al., 2021). In cities where poor water supply has eroded local confidence in service providers, technology can be used to share consumption, maintenance, and water quality data to improve transparency and re-establish trust.

Policy developments for smart (water) technology in Indian cities

There has been a growing interest in smart technologies in Indian cities stimulated by municipal strategic goals as well as national level programs. Early applications of smart water technologies were sporadic and motivated by different factors. In Mumbai, for example, the literature highlights two smart water technology proposals. The MCGM has initiated several large-scale projects since 2007. The Sujal Mumbai Abhiyan program (2007) intended to map Mumbai's water infrastructure and leak detection (Desai, 2012). This was followed by the AMR project in 2009. The AMR pilot and other water reforms at this time were guided by the recommendations in the pivotal Chitale committee report in 1994. This study, commissioned by the state government of Maharashtra, was undertaken following the water crisis in 1992. It recommended a number of measures for Mumbai city until 2021 pertaining to water supply augmentation, alternative sources, leak prevention, water recycling, management, and citizen participation (Desai, 2012). Success of these projects, however, is limited due to implementation issues (Singh, 2016).

Another early smart technology proposal in 2007 was examined by Anand (2020). This strategy was to install prepaid meters in new slum settlement areas (set up after 2000) as a way of extending water supply services to unrecognized residents. The decision to explore this technology was motivated by discussions at a stakeholder consultation meeting in 2007, with international experts from Johannesburg who had previously applied it in Soweto. However, faced with strong opposition from activists and hesitation from hydraulic engineers in Mumbai, the proposal was withdrawn. Activists learned about the shortcomings from their South African counterparts and feared it would lead to the privatization of water services. Meanwhile, engineers were concerned about the long-term issues if poorly managed prepaid meters cut off water supply, not to mention their cost. Only later in 2014, following a ruling by the Mumbai high court, was this proposal revisited as a way of extending water services for all slum residents in some form. However, 5 years on, Anand (2020) finds that none have been installed as scepticism from local engineers continues.

At the national level, India has also witnessed a top-town push for smart city development through the evolution of national level schemes aimed at urban development. Prasad & Alizadeh (2020) explain the evolution of these policies from infrastructure-focused to market-based. Technology here was seen to draw international investors. In particular, the Jawaharlal Nehru National Urban Renewal mission (JNNURM) and subsequent Smart cities mission (SCM)–both implemented through the Ministry of Housing and Urban Affairs–have played a major role in promoting and funding the development of smart cities.

The JNNURM targeted the rejuvenation of cities and towns across India between 2005 and 2015 (Ministry of Housing and Urban Affairs, 2021). Its goal was to fast-track reforms in urban infrastructure and service delivery to the urban poor (Roy, 2016). It was implemented in two phases. In the 2nd phase of this mission (2012 onwards), the concept of 'smart cities' was put forth. It promoted the use of Information Technology (IT) in projects which included water supply and sewerage (Sethi, 2012).

Smart city development in India was initially associated with greenfield cities where technological instruments was used to attract foreign investments, technology firms, and private real estate companies (Roy, 2016). In 2014, the smart cities concept was reframed for urban development. The smart cities mission, launched in 2015, includes both greenfield, brownfield, and pan city development projects. This 5-year mission aims to help establish 100 smart cities and towns in India. This conceptualization of smart cities refers to the long-term aspirational goals for urban services for its citizens, developed incrementally over time. Here, technology is integrated within the goal of developing institutional, physical, social, or economic infrastructure in a more efficient way for creating liveable, inclusive, and sustainable cities (Aijaz, 2021; Prasad & Alizadeh, 2020).

Dholera city in Gujarat was the first such smart city in India under this mission, developed in the Delhi-Mumbai industrial corridor. It was here that a SCADA (Supervisory Control and Data Acquisition) based smart water technology was used to manage waterlogging and wastewater problems. This smart city project, which began in 2012, has 3 phases, each 10 years in duration (Bang et al., 2020). Since then, several smart water technology projects have been selected by the mission. They include sanitation (Jabalpur, Kochi, Pune, and Coimbatore cities), preservation of nature water bodies (11 of 20 proposal studies), climate and disaster management (Ahmedabad, Bhubaneshwar and Vishakapatnam) projects (Prasad & Alizadeh, 2020). In total, 100 cities and towns were selected between 2015-2018 for technology-aided infrastructure projects across urban sectors. These projects are co-funded by governments at different levels and must also acquire external funding from financial intermediaries, multilateral organizations, and the private sector, etc.(Aijaz, 2021).

Both the JNNURM and SCM have faced criticisms. Evaluations of the JNNURM reveals limited impact due to lack of participatory planning, coordination between citizens and government, and the absence of suitable monitoring mechanisms–concerns that Roy (2016) argues were not considered in the follow up SCM. Recent assessments of the SCM shows only 50% project completion due to slow financial roll out and difficulties faced by states and union governments in mobilizing necessary funds (Aijaz, 2021). Prasad & Alizadeh's (2020) review of 20 proposals in the SCM furthermore, highlights the gaps in prioritization of environmental dimensions at the policy level compared to other dimensions. Although they argue that smart governance is the core of such projects in India, the failure to consider this dimension in smart city policies is concerning given the growing environmental issues in Indian cities. The location of some greenfield smart cities, for example, raise concerns about sustainability (Roy, 2016).

Aside from criticism from researchers and advocacy groups, local politics have also influenced participation in the mission. Conditions, such as the setup of a separate overseeing body known as 'Special Purpose Vehicles', was opposed by politicians in Mumbai and Navi Mumbai for fear that it would dilute the powers of the municipal authorities (Aijaz, 2021). Similarly, cost recovery is recovered from services charges such as water taxes in New Town was opposed for fears of inequitable development by the state of West Bengal (Aijaz, 2021; Housing & Land Rights Network, 2018).

Re-defining the role of smart technology for India's urban context

This chapter set out to examine an early smart water technology project in Mumbai, India. The pilot project reveals a variety of governance issues associated during the implementation of AMR technology. Ten years later, the insights from this pilot study continues to be relevant as India pursues its mission of creating 100 smart cities. In this concluding section, I reflect on the insights from India in a larger discussion of smart cities.

Historically, smart technologies, and in particular, smart water technologies like AMR, were adopted and tested in Europe and North American cities. More recently, they have emerged in developing countries, as demonstrated by the examples from India. These contexts very significant and must be considered in the application of smart technology projects (Prasad & Alizadeh, 2020). For example, cities in developing countries continue to face the challenge of meeting basic urban needs like water supply and addressing critical issues like poverty or climate change. Here, smart technology investments must be embedded in addressing these more fundamental issues instead of detracting resources away from them (Backhouse et al., 2020). A review of smart cities in South Africa (South African Cities Network, 2020) further highlights the role of the informal urban economy in these contexts and less mature IT and data management capabilities–both of which need to influence the design and success of smart technology projects. In India, ICT enabled urban services, for example, runs the risk of marginalizing large sections of the population who are unable to access them due to their socio-economic background or informality in living and employment situations (Roy, 2016). Meanwhile, Cheong et al. (2016) signals practical issues of power breakdowns that smart technology projects also need to take into account.

The review of smart technology applications in India gives importance to the role of governance. In some cities, particularly in the developing context, addressing institutional gaps is required before technological investments are made. Ideally, investments in institutions and technology should go hand in hand; however, the reality is that institutional capacity often lags behind technological advancements (Grey & Sadoff, 2007). Governments must prioritize and incentivize investments in institutional reforms (van de Meene et al., 2011). However, the capacity for institutional change depends on the socio-political conditions.

Moving forward, the adoption of smart technology in less developed regions and cities should be given more attention to by scholars. Smart technology use in India remains under-researched, especially when it comes to the governance of these projects. As a result, our understanding of the governance needed to support technological reforms is limited. Similarly, as the smart cities mission program wraps up in India, a need for monitoring and for evaluating projects in the long term is important. Here, Prasad & Alizadeh (2020) suggest assessing the proposals and vision statements of the smart cities in terms of addressing environmental challenges and economic opportunities from policy to implementation at the operational level.

Finally, recent utilization of smart water technologies in less developed contexts, calls for a need to revisit the original conceptualization of a smart city. Defining and evaluating smart cities through a purely technological lens ignores the socio-political motivations and processes that influences them (Roy, 2016). For example, in Indian smart cities mission, the focus is on smart governance; yet, critics point out the pitfalls of adopting a technocratic approach to governance. This is reflected also in the issues of funding, human resource capacity, citizen participation, and sustainability that appear to have impacted the success of this mission (Gulati, 2021). Prasad & Alizadeh (2020) argue for a contextualized definition to reflect the different urban realities and technology use in policy and practice. Instead, Roy (2016) suggests not viewing technology as the goal but as the means to improve the conditions for the most marginalized in order for smart cities to be inclusive.

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7.

Nakuru (Kenya)

Sponge City Nakuru

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Nakuru (Kenya)

Abstract

Rapid urbanization and population growth in Kenya's cities and towns creates a situation in which basic services and facilities often fall behind. Water supply and provision falls short due to dwindling resources. Flooding becomes a major issue due to insufficient stormwater management and buffer capacity. In a Sponge City, we aim to overcome these issues by deploying natural principles of water recharge, retention, and reuse in a built environment. This case-study of Nakuru presented in this article, focuses on three neighborhoods in cities with majority low-income households. It describes the formulation of the Sponge City building blocks in which the social engagement process is crucial. A 'mapathon', a combination of data collection tools, with google earth mapping and story-telling, was conducted to thoroughly understand the perspective from the residents, getting a real on-the-ground view and feel. It proved essential to build skills, commitment, and contribution. This case-study showcases that a sponge city must build upon locals and that the social engagement process with diverse multi-level stakeholders is at the backbone of a successful sponge city.

Key words: Sponge city, Sponge city, urban resilience, urban flooding, urban planning, urban water management, mapathon

Introduction

Globally, more people live in urban areas than in rural areas, with 55 % of the world's population residing in urban areas in 2018. In 1950, 30 % of the world's population was urban, and by 2050, 68 % of the world's population is projected to be urban (United Nations, 2018). This growth is the result of major economic and social transformations. Coupled with extreme weather events and prolonged drought periods, water supply and provision especially in urban areas becomes more and more challenging. While natural resources are depleting, the pressure on these very resources is increasing.

Rapid urbanization is difficult to accommodate in terms of basic services, facilities, and infrastructure, thus leading to the creation and sprawling of large informal settlements and slums where inhabitants often self-organize to compensate low public investment. These areas usually suffer from overcrowding, low employment, poor transport infrastructures, poor housing conditions, limited access to healthcare and education, and a lack of sanitation and waste management systems–hence generalized insalubrity (United Nations, 2018). As such, they are at great risk of entering the vicious circle of under-development and extreme poverty.

Kenya is one of these countries in SSA with rapid urbanization. It is expected to become a predominately urban country by 2033, with half of its population living in urban centers (World Bank, 2011). The growing urban centers all over the country are growing, especially in Arid and Semi-Arid Lands (ASALs) which are facing some pressing issues, including insufficient urban water provision, excess stormwater and flooding, and low quality of water. Each have a debilitating effect on the quality of life in many ways. For example, flooding destroys properties, leads to traffic congestion, and displaces people in affected areas.

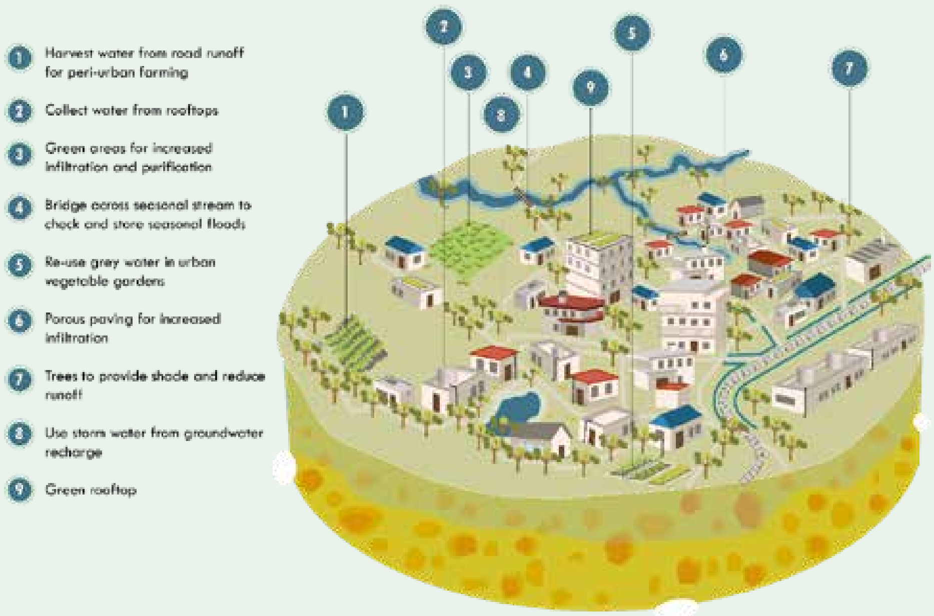
Sponge City seeks to provide a holistic solution to the myriad of pressing needs through the key principle of buffering extremes of high intensity short rainfall and long drought periods.

In the current planning paradigm, the idea is to drain out all the excess stormwater as quickly as possible. While in the dry season, water is supplied from an outside source, for instance, from a dam. However, a link between both stormwater management and water supply is often not made. This link is urgently needed, as current water supplies cannot meet the demand, while in the future, the gap between demand and supply is likely to grow bigger. Furthermore, quickly draining water out of the system creates high risk of flooding and erosion.

The Sponge City concept therefore takes a completely different approach and builds on the principle to buffer extremes. A sponge can soak up the water, retain it over time, and release it slowly in time of need. The real innovation of a Sponge City is not in single measures to be implemented, but in finding the right alchemy in which the measures are integrated in the urban landscape according to context and needs. Normally excess water, resulting from heavy downpours, is managed following the old paradigm of disposing water as quickly as possible. This approach implies a strong focus only on drainage lines to make water go out of the system. Nevertheless, this also implies that drains need to be oversized, with roaring costs, and that water that could be used otherwise is lost very quickly. The Sponge City concept aims at reverting this paradigm.

A sponge city can be described as a city "that can hold, clean, and drain water in a natural way, taking on an ecological approach" (O'Meara, 2015). Even though the context is substantially different, the concept is already being piloted in 16 cities in China, as a way to use landscape-based measures in order to address both water shortages and urban flooding. This entails the widespread adoption of water buffering techniques. The aim is to create an urban landscape that will function as a sponge. Sponge cities are thus characterized by natural retention, recharge, and reuse (3R).

Figure 1. Overview of Sponge City Interventions



These cities can save water resources, as well as protect and improve the urban ecological environment. It is a form of development that aims at providing a natural buffer for storm water runoff, and furthermore, provide for drainage, water harvesting, and storage facilities. In an urban environment, where concrete, stone, and asphalt are prohibiting water to infiltrate naturally into the ground, we integrate green infrastructure, such as recharge pits, bio-swales, and green roofs, to ensure water can be sustained within the town or city (see Figure 1). Annex 1 provides additional measures with short explanations.

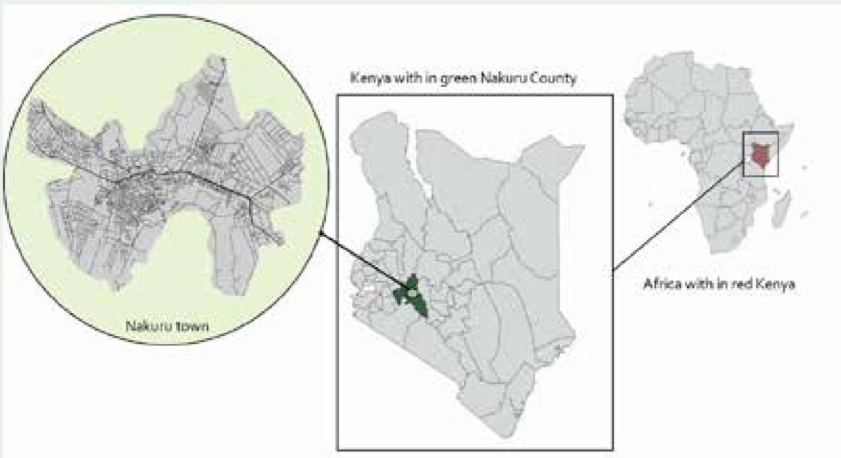
The sponge city concept results in sets of interventions that the environment and the residents will benefit from, either directly or indirectly. The interventions aim to (i) improve the water quality and quantity in a city, coupled with flood protection, and safeguarding of property and infrastructure; (ii) contribute to the restoration of degraded/abandoned landscapes and water sources, while also increasing economic goods and services such as urban farming through the utilization of the harvested stormwater; and (iii) increase urban community awareness on environmental issues, such as climate change and waste management and their well-being.

This paper presents the case-study of Nakuru City in Kenya, Africa. It elaborates on the main challenges, the sponge approach, the proposed solutions, the main findings and lessons, and finally policy implications and recommendations. We demonstrate an exemplary solution of a current Smart Water City project, thus contributing to an improved understanding of how fast-growing cities can transform into sponge cities and towns. We hope that more and more cities take this important step of becoming a sponge city or town.

Characteristics of Nakuru City

Nakuru is the 4th largest city of Kenya (population of 533,800, 2019 census) and is located at the bottom of the Great Rift Valley, just south of the equator, approximately 160 km from the capital city Nairobi. Nakuru County is one of the fastest growing areas in East Africa, expected to grow from 2 million in 2019 to 5.4 million in 2050, with an annual population growth of about 3.1%. According to a UN study released in 2011, Nakuru is Africa's fastest-growing city and the fourth in the world[1].

Figure 2. The location of Nakuru city in Nakuru County, Kenya, and Africa



1. www.wsup.com/content/uploads/2019/08/Sanitation_Nakuru_final.pdf

Figure 3. The location of the case-study areas London, Free Area, and Kaptembwo in Nakuru Town

Nakuru town is soon to be officially registered as a city and is strategically positioned to serve its hinterland, as it is centrally located with developed transport corridors to other centres. It has a relatively well-developed urban infrastructure which has enabled it to play a major and effective role in the region. The town is also a center for various retail businesses that provide goods and services to the manufacturing and agricultural sectors proliferate in the Rift valley of Kenya. According to a study by MajiData in 2011[2], Nakuru city has 49 low-income areas, comprising 57% of the population. These low-income areas are less served with water and sanitation services and highly affected by floods during rainy season. Figure 3 shows the low-income density in the three project areas: London, Kaptembwo, and Free Area in Nakuru city. The areas have several partitions which are commonly denoted as 'urban slums', and overall, the low-income density is higher compared to Nakuru city overall.

Nakuru town is facing increasing threats to its water supply, largely because groundwater sources are dwindling, while it provides 90% of the total water supply. Currently only 45,000m^3/d of water is available against a demand of 70,000m^3/d[3]. The demand for water is expected to rise significantly, with the demand for water reaching 191,000m^3/d in 2050 to serve the estimated population. The aquifers, rivers, and storm water drains in Nakuru city also feed Lake Nakuru. This lake sustains rich biodiversity, including pink flamingos that feed on algae blooms and has been designated a Wetland of International Importance by the Ramsar Convention[4].

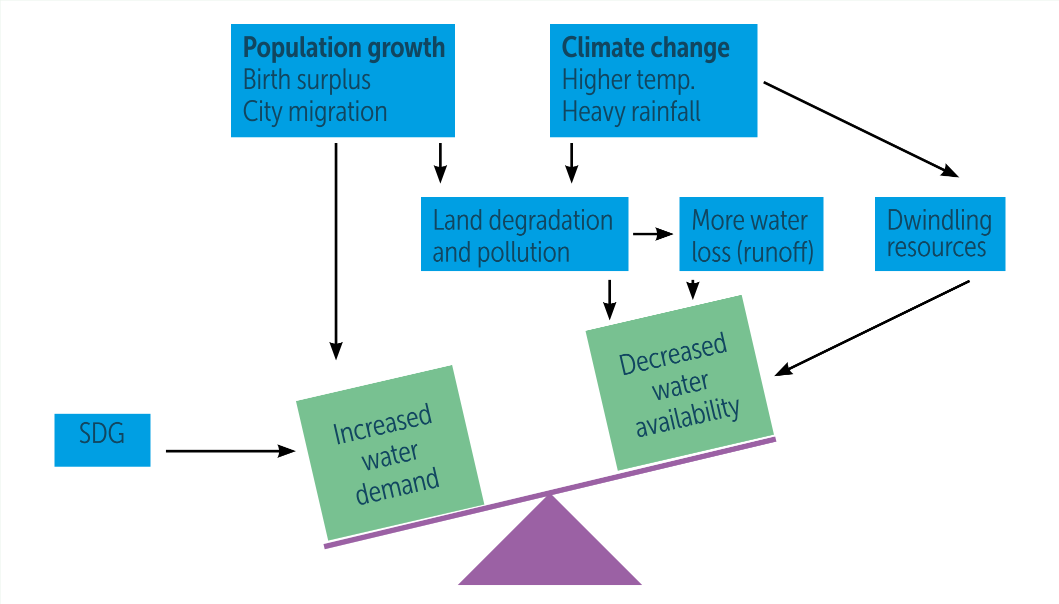
2. MajiData. (2011). MAJIDATA. majidata.go.ke
3. www.oagkenya.go.ke/getmedia/2b8dde69-743d-45c0-8329-bb6d352558e8/water-nakuru-water-and-sanitation-services-co-ltd2015-2016;.aspx?disposition=attachment
4. A Ramsar site is a wetland site designated to be of international importance under the Ramsar Convention. The Convention on Wetlands, known as the Ramsar Convention, is an intergovernmental environmental treaty established in 1971 by UNESCO, which came into force in 1975. It provides for national action and international cooperation regarding the conservation of wetlands and wise sustainable use of their resources.

Key urban water challenges addressed

At this moment, the predictions for Nakuru County clearly show shortage of water supply continuing to form an issue, while with the estimated population growth this shortage is likely to get bigger, especially for the town. This is not a stand-alone issue, as indicated in Figure 4.

This paragraph will first discuss the problems in clusters, after which underlying systemic issues are elaborated on as well.

Figure 4. Bigger pictures of interconnected issues



First, Nakuru is both fast growing and fast sprawling, which is a big challenge for urban planning, water supply, and sanitation. Water demand is already higher than supply and recent data indicate that resources in Nakuru city area are overexploited. Amongst others, this is due to minimized direct recharge in the city, particularly due to abundance of hard surfaces, allowing little infiltration. Moreover, these hard surfaces promote extreme runoff, resulting in floods which is another major issue in Nakuru city. As one person put it: "Why do we look at the water flow past us in floods when it rains, only to chase it afterwards with donkeys when the rains have stopped?" Especially in low-income areas (London, Kaptembwo, and Free Area), connected water supplies cannot meet the demands: 71% of low-income population experiences insufficient water supply, while 29% is not connected at all. Buying additional water is difficult for the population due to high price levels. Second, due to climate change extremes, such as long drought periods coupled with high runoff due to urban sprawl, existing groundwater sources are dwindling. While the existing groundwater sources contain high levels of fluoride, making it unfit for drinking. Third, the town faces a myriad of technical issues: Lack of green spaces, blocked drainages, flooding, insufficient sanitation facilities, and poor solid waste management. Fourth, the town faces a myriad of governance and financial issues, such as a lack of timely spatial planning, ad hoc solving of issues in silos, insufficient investment capital, reliance on big dams, loads of well-written policy documents, but little concrete action on the ground and a lack of accountability.

Finally, there are several underlying systematic gaps at play which hamper sustainable urban water management. Firstly, government programs tend to focus on large-scale interventions that are not connected to each other, taking a long time to establish, and are often not as successful as planned. Secondly, a common perception occurs that the solution should come from 'the others' (the community members look to the county government, the county government looks to the national government and donors, and utilities wait for interventions from donors, the national government and other agencies). Along with that, there is often no clear problem holder; the problem affects us all and needs to be solved by all. This leads to lack of agency in solving the problem. Thirdly, there is a focus on tangible short-term issues like fighting COVID-19, rather than long-term threats, like climate change. Fourthly, water harvesting and sanitation structures are mostly organized on individual basis rather than at a community level. Lastly, some vulnerable groups are left behind in planning and catering for Water, Sanitation, and Hygiene (WASH) services, whereby provision of services through youth and women to combat poor livelihoods and high unemployment are not yet enabled.

Innovative Smart Water technology solutions proposed

Despite the difficulties which the described issues bring with them, these challenges also provide huge opportunities in multiple ways, the sponge city concept is designed to utilize the opportunities, through (1) deploying tailored natural 3R methods and integrate this into a built environment; (2) focussing on low-cost, high-impact solutions that can be implemented by a wide range of stakeholders; (3) integrating green infrastructure in urban planning and design; and (4) creating a strong social movement through intensive engagement of multi-level stakeholders.

Figure 5. A range of aspects to consider when developing a Sponge Town

A Sponge City for instance provides the opportunity to create urban green spaces, which both contribute to water management as well as to recreation. In summary, a Sponge City means improved water management, improved safety, longevity of infrastructure, and beautification of cities. The overall aim is to create a better living place, one that is vibrant, green, and attractive.

In the case-study, we (i.e. the project team consisting of Nakuru County Government, NAWASSCO, VEI, and MetaMeta) selected three areas, London, Free Area, and Kaptembwo, (see Figure 6 and Table 1) in Nakuru that are linked to each other topographically and have a large share of low-income population–a total population of 105,608 people. We conducted a formulation phase for Sponge Town Nakuru's preparation, aiming to leverage ideas and solutions that are created by the people living in the town itself. Our aim is to organize the building blocks with which the residents, private sector, and governments can build their own sponge city.

Figure 6. Low-income density of estates/villages within the study areas

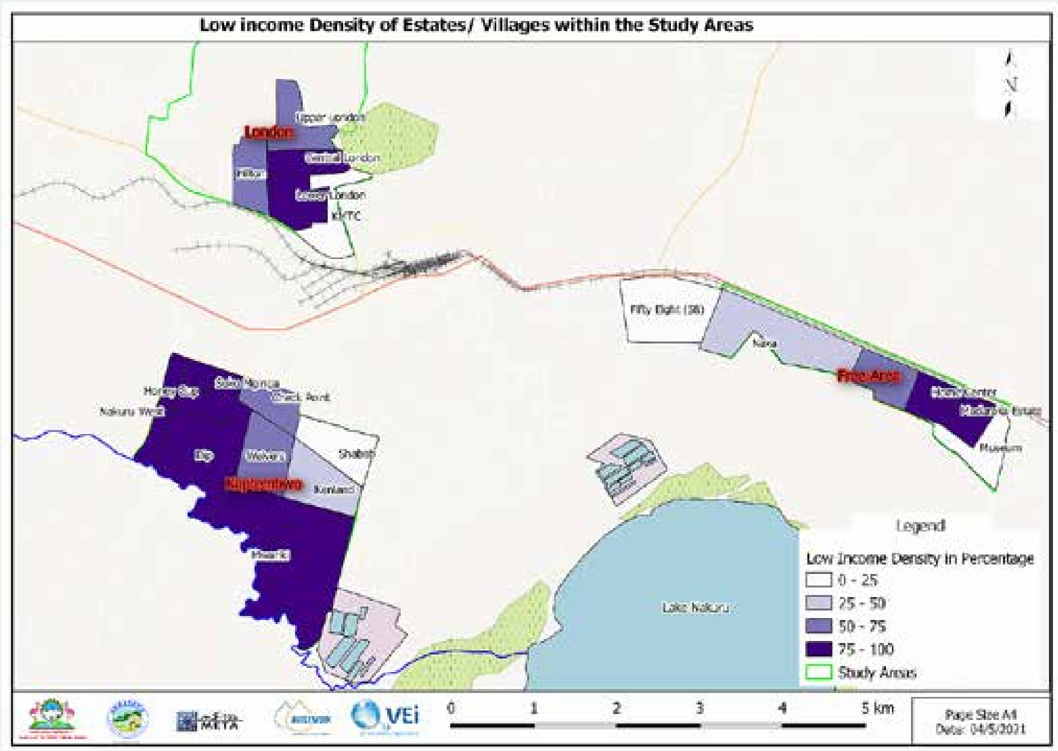


Table 1. Study Areas Characteristics

	Free Area	Kaptembwo	London	Total	Average
Population Size	46,004	43,521	16,083	105,608	
Number of HHs	14,469	15,351	4923	34,743	
avg. HH size	3.18	2.84	3.27		3.09
Population of low income	21,137	36,695	3,133	60,965	
% low-income	45.95	84.32	19.48		49.91

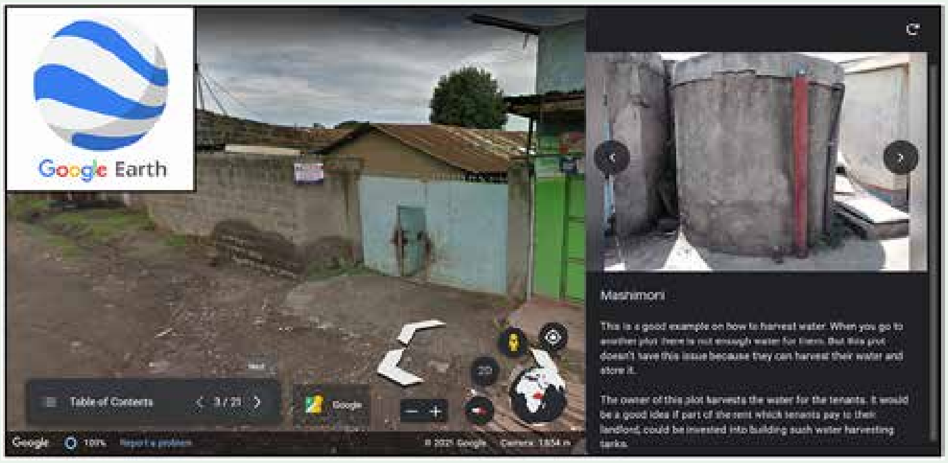
The 'mapathon' as a tool for community engagement

During the formulation phase, we have connected to many target stakeholders (180 in the baseline survey, approx. 150 through FGDs with community target groups and SMEs, 24 in the citizen Mapathon, 45 in the exchange visit and 20 in government meetings).

Figure 7. Mapathon as a tool for community engagement

Each has shared various ideas, as well as explained its own role to play and their contribution to make. In Nakuru, we used new tools to improve the inclusion of the 'voice of the resident' in urban planning. We did this through a mapathon, an event where residents are trained on digital skills to collect, share, and monitor data. These residents took us along on a journey through their neighborhoods. They made us look through their eyes, and better yet, they captured their stories and ideas in such a way that we could share it with other key stakeholders and decision makers who may not have the time or the ability to travel to their neighborhoods, but who do make major decisions which influence the quality of life in these neighborhoods. We used two platforms through which local knowledge and outer space can be connected: Google Earth combined with Kobo Toolbox.

Flooding and water shortage particularly occur in the low-income areas in the wards Kaptembwo, Free Area, and London. We had detailed discussions with residents from these areas on the two topics and the concept of 'sponge city' – applying 3R (retention, recharge, reuse) in the city to reduce these issues. These discussions were held with several community groups who were formed by residents to create change in their neighborhood and included residents from different backgrounds, abilities, age groups, and gender. The discussions include an introduction of the sponge city concept, brainstorm sessions, and planning sessions using maps of the areas. After these discussions, the residents traversed their neighborhoods in small groups armed with their phones and tablets to share what specific issues related to flooding and water shortage occur. However, while it is often easy to find what is wrong, it is more challenging to find out what to do to alleviate the problems. Therefore, when reporting on the issue, the ward residents also came up with potential solutions. These stories and ideas were collected through an app called, KoBo Toolbox, in which each story includes a GPS point and can be reported through photos, videos, and/or text. These information points were then transferred to Google Earth, resulting in a dynamic and visual map. Google Earth is known by many as an interactive map of the world that enables zooming in and out of areas which can be observed through highly detailed satellite images. However, the platform also includes a feature to make your own 'project'. This project creation tool is very user friendly and was used by the residents to turn their collected KoBo Toolbox data points into a cohesive story. They selected the most relevant pictures and videos and added descriptions. The viewer of this story can now click on 'next' and in doing so follow the residents on their walk through their neighborhoods, zooming in and out of areas with major issues and areas with great opportunities for improvements.



The result of this 3-day mapathon is a digital story where you can see the neighborhoods through the eyes of the residents. Through pictures, videos, and stories residents show us issues, good examples, and new solutions. You can join them on a journey through their neigbhorhoods by clicking here[5].

Technical and non-technical requirements for the implementation of the smart water technologies

The aim of our formulation phase is to prepare all stakeholders to transform Nakuru into Africa's first Sponge City by creating a critical mass of local support, investments, knowledge, partnerships, innovation, and commitment that will make a Sponge City and keep it running. The innovation does not lie in one single measure, rather the added value of a Sponge City lies in the holistic approach with a key role for residents, businesses, and authorities. The main lessons and findings include the following:

For the success of a Sponge City, social engagement is crucial. It is essential to include, engage, and work together with diverse and multi-level stakeholders. Each person has something to bring to the table, and it is vital to facilitate constructive discussions and collaborations between these different stakeholders. The social engagement process is as important as the technical solutions. Sponge city involves community in the entire process to ensure technologies are most appropriate to their particular settings, and that they are informed on the available options and the consequences of these choices on the long-term–in terms of maintenance, safety, and environmental impact. In this way, we respond to direct demand of communities in the delivery of facilities.

5. earth.google.com/web/data=Mj8KPQo7CiExNGJSR01mdkJ5RjhyYXFrSTVmTXphbm5HM FBKTFpWdGsSFgoUMDMxQTA2Rjk1RTE5N0I4OUZENTY

Figure 8. Snapshots from Nakuru Town where residents developed ideas and/or solutions

Furthermore, key stakeholders must be strengthened regarding their capacity to make informed technological choices. Hereby, it is important to strike a balance between necessary safety and quality standards on the one hand and local resources and management capacity on the other hand. Pay attention as well to strengthen the production, construction, and maintenance capacities of local providers as to be capable to respond to demands, opportunities, and ideas from consumers and investors. Sponge city service delivery will be simple, affordable, and adequate, linked to what is practiced and available. This is done by ensuring that constructions blend in with the local building style, using locally available materials and skills, meeting the need of women, children, the elderly, and handicapped.

We use a rights-based approach. Through local lobbying, advocacy, and budget tracking, communities will be empowered to express their needs and demands to the authorities for adequate budget allocation and use. Civil society organizations will be supported to translate needs and demands at grass roots level into advocacy messages to influence county government policies and budget allocations, as well as function as watchdog to hold responsible authorities accountable.

Financing is required to provide and sustain Sponge City investments at city, private, public, community, and business level. Market forces must be recognized and appropriately considered, so that small enterprises have the opportunity to flourish when properly addressing water and sanitation in a locally regulated business sector. The main financial principle of a sponge city is Local Finance First. We work towards models in which investment costs are covered as much as possible through local funding sources (consumers, the public sector, private investors, through household contributions, recurrent tax revenue, fee systems, decentralized funds, and loans from local finance institutions, like banks).

Local/regional government must be at the forefront and take charge of the interventions, enabling to leverage on existing policies and institutions.

In Nakuru, the County is upfront in improving the enabling environment by opening opportunities for communities and private sector players to engage and improve the resilience of the city. The County recently assented The Nakuru County Water and Sanitation Services Bill, 2020, which seeks to provide a legal framework to guide water and sanitation service providers. In the bill, Sponge City is explicitly mentioned as intervention towards water sustainability and safety. Furthermore, an Integrated Water, Sanitation, Faecal Sludge and Wastewater Master Plan for Nakuru County is being developed. In addition, the County has passed 3 water bills, among them The Nakuru County Climate Change Bill (2020).

Policy implications and recommendations or next steps

It is not easy to foresee how a city or city will evolve, especially not a fast-growing one in Kenya which often evolves very organically. Therefore, we don't want to get lost in future-blueprints; rather, we ensure the building blocks are future-proof. In order to do so, we must develop progressive legislations that create an enabling environment (e.g. water sensitive construction permits and installing Community Environmental Volunteers) and that make large scale public interventions possible (e.g. blended finance, green taxes).

A second recommendation is to put the residents of the town or city in the driver's seat. They are the ones living there; they will feel the change day-by-day and are always 'on-site' to make a change. Through a process of intensive and inclusive social engagement, we lay the foundation for sustained commitment and contributions.

A third recommendation is to focus on low-cost technologies, with high impact, which can be provided by local businesses and skilled people. When you source from within, a town or city can also be developed economically.

Lastly, we encourage you to be creative in engaging people and making it fun; this opens both doors and minds. The mapathon is an example of an inspiring tool in the project that ensured collaboration, ownership, and valuable input from the participants straight from the start. Next, it can be used to track the progress of the project, to monitor the project, and evaluate it, especially if the participants have their own smartphones. This can be done continuously to see where the project needs to be tweaked and identify where things are not working out as planned. Finally, it is a great method for reporting. It is often more enjoyable and engaging to travel through a google earth story than to get stranded in a 10,000-word report.

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Acronyms

3R – Retention, Recharge and Reuse
ASAL – Arid and Semi-Arid Land
FGD – Focus Group Discussion
HH - Household
NAWASSCO – Nakuru Water and Sanitation Services Limited
SDG – Sustainable Development Goal
SME – Small and Medium Enterprise
SSA – Sub Saharan Africa
WASH – Water, Sanitation and Hygiene

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Summarized inventory of sponge city techniques

Measure	
Rooftop water harvesting	Traditional system to harvest runoff water, mostly for domestic use.
Recreational wetlands	Develop a water retention and storage site in combination with a recreational park.
Urban farming	Enhance growing of vegetables in a small, efficient garden, with the water harvested from the roof, or from the compound. Possibly in combination with grey water reuse.
Groundwater / wellfield recharge	Deploy tube-well recharge to augment groundwater sources, especially those already in use, but with low yield.
Sand dams and sub-surface dams	Barriers in sandy seasonal streams are a simple way to augment the amount of water stored in the sand, which can be harvested through simple wells and scoop holes.
Bioswales (bunds)	Can be used to trap sheet runoff and augment infiltration.
Raingardens	As alternative or in conjunction to rooftop water harvesting, the water can be used to nurture homestead/school gardens.
Road drifts	Low causeway can become a simple way to recharge shallow groundwater while decreasing road damage.
Culverts	Culverts orientation, number and design commonly define drainage patterns and can be therefore engineered to channel water to recharge/retention areas.
Irish bridges	Irish bridges can be turned into multi-functional infrastructures where they double up as sand dams, storing sand, thus storing water and acting as a buffer against floods.
Small reservoirs	Multipurpose small reservoirs can retain water to be used during the dry season. Special care must be paid to water quality.
Recharge basins	Storm water can be retained in permeable basins that help to recharge shallow groundwater and to buffer peak discharge.
Permeable paving	Permeable paving with cobble stones is functional in decreasing peak runoff and in increasing infiltration.
Water from roads	Roads divert and concentrate big volumes of runoff water. The road surface and the adjoining drains can be used to redirect water for recharge or for productive uses.
Roadside planting	Storm water can be diverted to trees, strategically planted along roads.

New York City (USA)

New York City: A Smart Water City case study

Alan Cohn and John Brock

New York City (USA)

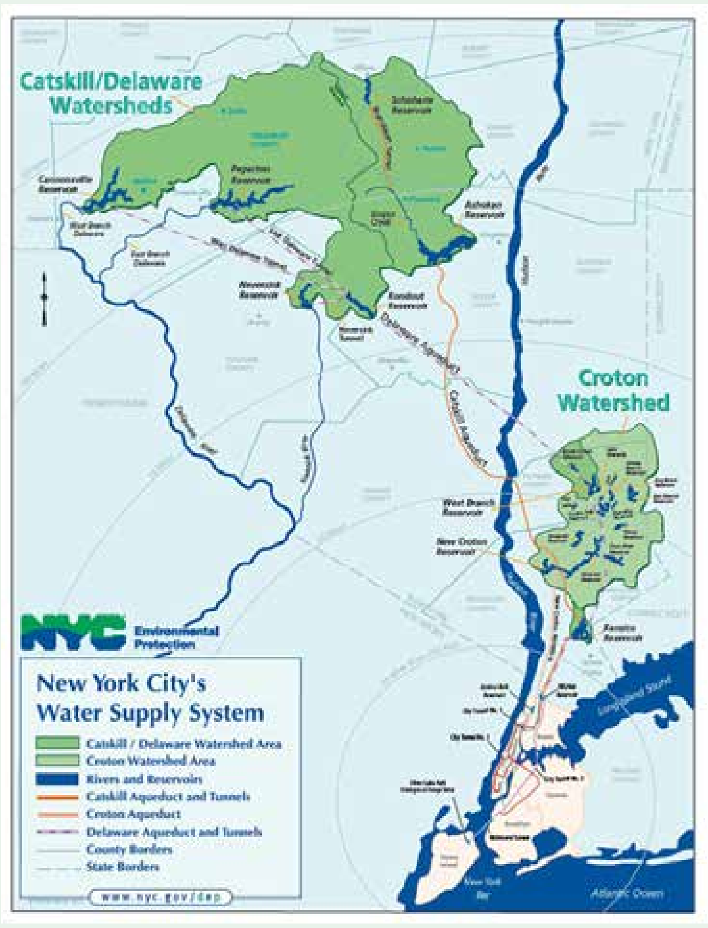
Abstract

New York City faces a variety of urban water challenges that require innovative solutions. As New York City's water and wastewater utility, the Department of Environmental Protection (DEP) holds the critical mission of enriching the environment and protecting public health for New Yorkers by providing high quality drinking water, managing wastewater and stormwater, and reducing air, noise, and hazardous materials pollution. Longstanding challenges and stressors, including budgetary pressures, make it more difficult for DEP to balance regulatory requirements with the growing need to invest in climate resiliency and sustainability, while also maintaining customer affordability. Innovative water technology solutions that consider all aspects of water management are necessary for DEP to optimize resources and achieve multiple objectives.

Introduction

New York City's water supply system is comprised of 19 reservoirs and three controlled lakes spread across a watershed that spans over 5,000-square kilometers (see Figure 1). Today, DEP delivers approximately 3.8 billion liters of high-quality drinking water to more than eight million NYC residents, visitors, and commuters, as well as to one million upstate customers. Throughout its history, New York City's ability to provide a reliable source of water for its citizens has allowed it to grow and develop into a great urban center.

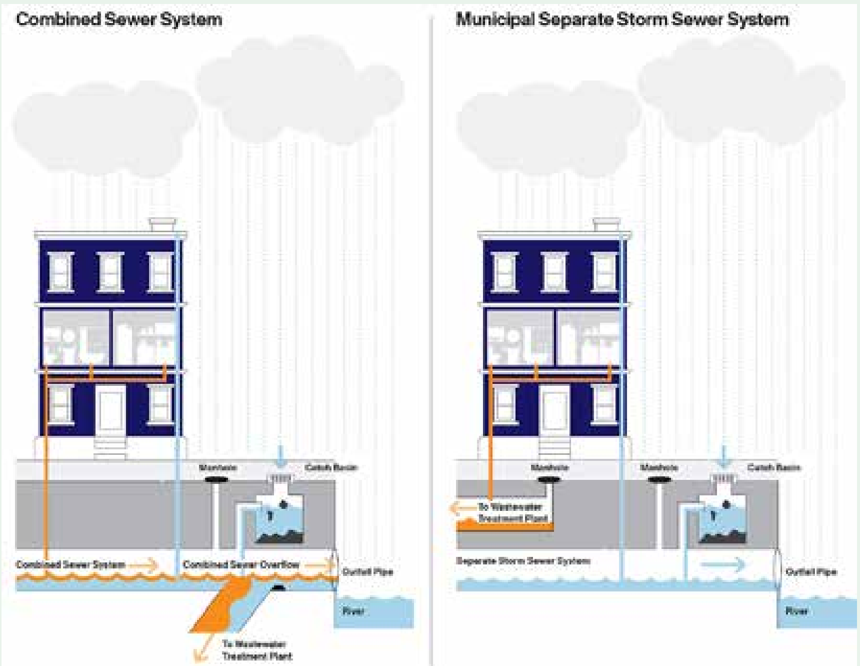
Figure 1. New York City's Water Supply System



New York City's wastewater treatment system consists of over 9,500 kilometers of sewer pipes, 135,000 sewer catch basins, 495 permitted outfalls, and over 90 pumping stations that transport wastewater to one of the city's 14 wastewater resource recovery facilities located throughout the five boroughs. DEP treats approximately 5 billion liters of wastewater per day.

Like many older cities, New York City is partially served by a combined sewer system in which pipes accept a combination of sewage and stormwater flows. The combined sewer system serves approximately 60 percent of New York City by land area. In dry weather, practically all of New York City's sewage is treated. During rainfall, however, the added volume of stormwater can exceed the capacity of the sewer system. This can result in untreated overflows from relief structures that are designed to protect the biological treatment process in treatment plants and to prevent sewage backups and flooding. This is what is known as combined sewer overflow (see Figure 2), or CSO, and can have effects on water quality and the recreational use of local water bodies.

Figure 2. Combined Sewer Overflow During Wet Weather



In many regions, including the Northeast United States, a higher percentage of total annual rainfall is occurring in the form of heavy downpours. Climate projections suggest that annual precipitation in New York City will likely continue to increase (NYC Panel on Climate Change, 2015). DEP's current stormwater programs have been successfully managing the rainfall events for which they are designed. However, typical stormwater infrastructure is not designed to manage heavy downpours, mainly due to space constraints. As New York City continues to experience increases in the frequency of heavy rainfall events which exceed the capacity of current stormwater infrastructure systems, increases in combined sewer overflows and flooding may also occur.

Additionally, as New York City continues to grapple with the consequences of climate change, opportunities to ensure the resiliency and reliability of our water supply system must continue to be identified. Reducing water demand benefits the water supply system and New York City at large by increasing flexibility in operations, reducing our energy footprint and greenhouse gas emissions (from treating less drinking water and wastewater), and keeping water bills affordable. DEP is the lead agency not only for delivering drinking water, but for ensuring its sustainable use by optimizing existing resources and maximizing co-benefits with a holistic, One Water approach.

Characteristics of the city

Location: Northeast United States
Size: 784 square kilometers
Density: 70,000 people per square kilometer (NYC Department of City Planning, 2021)
Socio-Economic development:

- GDP: $1.7 trillion, GDP per capita: $71,084 (Bureau of Economic Analysis, 2017)
- Life Expectancy: 81.3 (NYC Department of Health and Mental Hygiene, 2018)
- New York Literacy Rate: 77.9% (World Population Review, 2021)
- Unemployment Rate: 10.6% (NYS Department of Labor, 2021)
- Speed of urbanization: 2.7% increase from April 2010 – July 2018 (NYC Department of City Planning, 2018)

Key urban water challenges

Water supply

The New York City watershed is in portions of the Hudson Valley and Catskill Mountains with areas that are as far as 200 kilometers north of New York City (see Figure 1). Since 2009, average daily demand has been below the 1960s drought-of-record (when demand was approximately 4 billion gallons per day) with demand in 2020 hitting a 60+ year low, due in part to the COVID-19 pandemic and associated closures. While New York City is considered water-rich, DEP has actively been seeking ways to reduce drinking water demand and to prepare for a major infrastructure improvement project to repair leaks in one of the city's largest water distribution tunnels. In addition to providing a critical buffer prior to and during repair work, lower demand will also help optimize reservoir water levels during times of drought, offset energy and greenhouse gas emissions associated with pumping and treatment, and reduce flows to the sanitary and combined sewer systems (NYC Department of Environmental Protection, 2021).

Harbor water quality

As stormwater flows, it sweeps up pollutants such as oils, chemicals, sediments, pathogens, and trash. During wet weather, these pollutants can flow into the city's waterbodies and greatly impair water quality. DEP oversees a broad citywide effort to better manage stormwater to improve the health of our local waterbodies and prevent flooding. Since 1909, the city has monitored the waterbodies of New York Harbor through its Harbor Survey Program which collects water quality data and tracks progress of improvements efforts. Investing in new infrastructure, while also pioneering advancements in wastewater treatment, water reuse, and resource recovery is critical for the continued improvement of the city's waterbodies. Over the last several decades, the city has invested more than $45 billion in the construction and upgrade of critical wastewater and drainage infrastructure to improve the health of our city's vital ecosystems. In recent years, the city has committed an additional $10.6 billion to continue the legacy of innovation and investment to usher in a new era of environmental protection for its waterbodies. Today, New York Harbor is cleaner than it has been at any other time in the last 100 years, but more work is needed (NYC Department of Environmental Protection, 2018).

Climate resiliency

New York City experiences combined sewer overflows with each moderate rainfall and flooding during heavy rain events. Extreme rainfall events are becoming more frequent and disruptive in New York City and beyond. According to The National Climate Assessment, which summarizes current and future impacts of climate change on the United States, the heaviest 1 percent of daily rainfalls increased by 70 percent in the Northeast United States between 1958 and 2012. Climate projections suggest that this trend will continue, and that New York City will likely experience increased precipitation in the future. The New York City Panel on Climate Change (NPCC) anticipates that by the end of the century, the city could experience as much as 25 percent more annual rainfall than today and 1.5 times as many days with more than one inch of rain (NYC Panel on Climate Change, 2015).

Climate change will affect water resources in New York City from the upstate watershed to New York Harbor. It will demand an innovative response by the city's water managers, planners, and regulators to meet stringent water quality standard requirements while advancing the city's sustainability and resiliency objectives. As the largest municipal water utility in the United States, in a city with over 830 kilometers of at-risk coastline and approximately 5,000 square kilometers of watershed protecting drinking water, DEP must find new ways to maximize investments by incorporating the latest climate science, affordability, population, and water demand projections, tightening regulations and associated uncertainty into our planning.

Innovative smart water technology solutions

New York City Water Demand Management Program

DEP's Water Demand Management Plan identifies six key strategies for managing water demand in New York City and details specific initiatives to be implemented through 2023. Since the release of the plan in 2013, DEP has invested over $50 million to achieve water savings of over 60 million liters per day (MLD) and continues to make progress towards achieving the program's 75 MLD water savings goal.

DEP utilizes automatic meter reading technology (AMR) to track water consumption and progress across the Demand Management Program. In 2009, DEP launched its AMR program and largely completed that effort in 2012. DEP has installed approximately 829,000 AMR transmitters, representing 99% of DEP's AMR installation target. As DEP moved to AMR, meter readings changed from four times a year to at least four times a day and often, hourly. This has allowed DEP to establish citywide water consumption trends, identify opportunities for conservation, detect leaks, and track the progress of water conservation programs. AMR also allows customers whose accounts have been upgraded for AMR to access details of their water usage through DEP's website.

As part of the Demand Management Program, DEP established partnerships with fellow city agencies to ensure that water is used as efficiently as possible in city-owned facilities. These programs and partnerships have allowed DEP to advance smart water technologies, such as water reuse. Water reuse reclaims water from a variety of sources and treats and reuses it for beneficial purposes. This can provide alternatives to existing water supplies and be used to enhance water security, sustainability, and resilience. DEP has implemented several innovative water reuse projects with our municipal partners. DEP also established a Water Conservation and Reuse Grant pilot program as incentive to private properties. While the primary goal of this program is to conserve potable water, on-site water reuse also offers opportunities for achieving co-benefits and is an important part of DEP's One Water approach towards managing water resources. For example, water conservation and water reuse projects reduce flows to the sewer system and wastewater facilities, which can contribute to reductions in combined sewer overflows.

For example, DEP worked with the New York City Fire Department (FDNY) to install a new facility to recycle water used to test and calibrate the meters and equipment of the fleet's pumper truck rig. FDNY's vehicles need to be tested prior to being accepted into the fleet to make sure they are in working order and once a rig is in service, require testing and calibration once a year. These tests would typically use water that would then drain directly to the East River, or to catch basins connected to a sewer. To improve this process, the new water recovery facility creates a closed loop system, so that used water can be recovered and reused, instead of relying solely on potable water. This project is estimated to save over 110,000 liters of water per day.

DEP also supported a reuse project in partnership with Brooklyn Botanic Garden (BBG) by providing funding for a pump system as part of a stream restoration project that conserves water and reduces discharge to the combined sewer system. The stream restoration project, called Belle's Brook, reduces BBG's outdoor consumption for its water features from over 80 million liters per year to less than four million liters, a reduction of over 200,000 liters per day.

DEP is currently working with the Central Park Conservancy and Department of Parks and Recreation on the North End Recirculation Project in the iconic Central Park. This project is estimated to save over 3 MLD of potable water by recirculating stormwater rather than potable water between the park's northern waterbodies. In addition to the potable water reduction, other benefits include improved water quality in the park's northern waterbodies and combined sewer overflow reduction of over 10 million liters per year to the East River.

To promote additional measures on private properties, DEP is also offering the Water Conservation and Reuse Grant pilot program to offset capital costs for projects that save at least 3.7 million liters of water per year. As part of this program, DEP is supporting a first-of-its-kind, 1.5 MLD district-scale reuse system that not only reduces demand on New York City's potable water supply system, but also cuts flows to the combined system by an estimated 99 percent. Currently, DEP is seeking new and innovative ideas, technologies, and approaches for how stormwater can be successfully captured and treated to optimize benefits, reduce risks to public health, and promote co-benefits (NYC Department of Environmental Protection, 2021).

Wet weather management and climate resiliency

DEP has been committed to investments and policy changes for drainage improvements, green infrastructure, and on-site stormwater management, which have the added benefit of reducing the amount and slowing the rate of stormwater entering the city's sewer system. The 2010 Green Infrastructure Plan provided a detailed framework and implementation plan to meet the twin goals of better water quality in New York Harbor and a livable and sustainable New York City. Green Infrastructure diminishes the impacts of heavy rain events by capturing the rain runoff from normal rain events. The Plan launched the New York City Green Infrastructure Program, which has implemented over 10,000 green infrastructure practices, managing over 1,200 "greened acres" (approximately 3,500 cubic feet) which are constructed or currently in construction (NYC of Environmental Protection, 2020). Through the Program, DEP has formed important relationships with city agencies and expanded sustainable stormwater management principles to streets and public spaces. The Program has three primary implementation areas:

- **Right-of-Way (ROW) Green Infrastructure**: In 2012, DEP launched area-wide green infrastructure projects, in partnership with other city agencies, and has achieved most of the stormwater management through the installation of ROW practices such as rain gardens and infiltration basins.
- **Public Property Retrofits:** DEP, in partnership with other city agencies, is developing green infrastructure projects on almost 200 publicly owned properties.
- **Private Property Initiatives:** DEP's Green Infrastructure Grant Program offers funding for the design and construction of green roof retrofits on private property in New York City.

In addition to traditional green infrastructure, innovative drainage solutions, such as the Bluebelt Program, have also been developed. Bluebelts are ecologically rich and cost-effective drainage systems that naturally handle the runoff that falls on our streets and sidewalks by preserving natural drainage corridors including streams, ponds, and wetlands, and enhancing them to perform their functions of conveying, storing, and filtering runoff precipitation or stormwater. As New York City prepares for rising sea levels and heavier rains due to climate change, Bluebelts offer a natural and effective solution for stable and sound stormwater management. However, while Bluebelts are effective, they still do not address larger, extreme storm events and additional means are required to handle larger storm volumes.

In 2015, DEP partnered with the City of Copenhagen to share knowledge on innovative solutions that can prepare the New York for heavier and more frequent downpours or "cloudbursts" brought about by climate change. As part of this collaboration, DEP initiated the Cloudburst Resiliency Planning Study to assess risks, prioritize response, develop neighborhood-based solutions, and assign costs and benefits for managing cloudbursts. As a result of the Cloudburst Resiliency Planning Study two pilot projects were identified in the neighborhood of Southeast Queens, an area for which the city has committed $1.9 billion to build a comprehensive drainage system and alleviate flooding and to help demonstrate the feasibility of implementing the cloudburst approach.

One of these projects is located at the South Jamaica Houses, which is an 8-block public housing campus in South Jamaica, Queens, and is home to approximately 2,600 residents. This project will maximize stormwater capture for almost 6 cm of rainfall per hour. In addition to flood mitigation, another focus of this pilot is to show how cloudburst infrastructure can go beyond just managing stormwater and offer many co-benefits by reimagining the urban fabric of communities. This innovative approach utilizes interconnected, below- and above-ground rainwater conveyance and storage. Cloudburst projects aim to supplement ongoing sewer buildouts and act as a buffer for storms not captured by sewers due to the size of the storm, or the lack of fully built-out storm sewer infrastructure (see Figure 3). This would reduce flooding in areas where traditional infrastructure takes longer to implement and will alleviate chronic flooding of adjacent areas (NYC Department of Environmental Protection, 2017).

Figure 3. As part of the South Jamaica Houses cloudburst pilot project, an existing basketball court will be excavated to create underground water storage and repair the surface. The new "cloudburst" design will lower the basketball court, allowing it to fill with water during extreme rain, and will provide a new seating area for residents.

In 2021, New York City Released the Stormwater Resiliency Plan, which outlines the city's approach to managing the risk of extreme rain events. Truly holistic planning for rain-driven flooding involves consideration of both large storm events and the chronic worsening of average conditions. For this reason, the plan addresses emergency response procedures as well as accounting for increasing rainfall in standard design and long-term planning of stormwater infrastructure. The plan commits to four goals that optimize emergency response to extreme rainfall events and ensure that future city investments manage this climate risk:

1. Inform the public about flood vulnerability from extreme rain;
2. Update NYC's flash flood response procedures to prioritize response in vulnerable areas;
3. Advance policies that reduce urban flooding as well as research that informs future risks;
4. Leverage stormwater investments to help manage future flood risk from extreme rain and sea level rise. Future investments can alleviate flooding throughout the city.

For this plan, NYC performed a first-of-its-kind citywide analysis of rainfall-induced inland flooding. Modeling this type of flooding requires consideration of multiple urban flood drivers including the development of representative rainfall hyetographs (a graphical representation of the distribution of rainfall intensity over time), consideration of tidal conditions and climate change, and an understanding of localized sewer network capacity and overland drainage pathways. These components are complex individually, and when combined and considered on a city-wide scale, require detailed hydrologic and hydraulic (H&H) models to evaluate and predict flood risk. Through this modeling effort, New York City produced stormwater flood maps that depict areas of predicted rain-driven flooding to help New Yorkers understand and prepare for this risk. These maps will help individual New Yorkers understand risks related to extreme rainfall events and the city to prepare for future long-term investment and target that investment towards implementing innovative solutions in the most flood-prone areas.

New York City is working to improve water quality and address urban flooding through an integrated stormwater management approach that ensures long-term resiliency and reliability for communities. Interconnected networks of stormwater infrastructure that work together to convey, store, and filter stormwater can play an important role in mitigating flooding and improving water quality, as well as provide several co-benefits to communities (NYC Mayor's Office of Resiliency, 2021).

In addition to infrastructure solutions for managing stormwater, DEP offers innovative technologies to engage the community. In 2016, DEP launched the Wait... Program, which is a voluntary text messaging program that notifies participants when to use less water during a heavy rainstorm to reduce sewer overflow to waterways. Wait... engages an active environmental community and helps illustrate that individual actions can have an impact on waterbodies. During heavy rainstorms, the Wait... Program sends text notifications to participants informing them that sewers are at capacity and to wait to use water until after the rain. Participants then receive a second text alert notifying them that the rain has stopped, and they are clear to resume using water responsibly. After two successful pilot programs, DEP is currently in the process of developing a smart phone application for the Wait... program that will be deployed citywide.

Technical and non-technical requirements

CSO Consent Order: On March 8, 2012, the New York State Department of Environmental Conservation (DEC) and DEP signed a ground-breaking agreement to reduce CSOs using a hybrid green and gray infrastructure approach. As part of this agreement, DEP agreed to develop 10 waterbody-specific Long-Term Control Plans (LTCP) plus one citywide LTCP to reduce CSOs and improve water quality in NYC's waterbodies and waterbodies. The goal of each LTCP is to identify the appropriate CSO controls necessary to achieve waterbody-specific water quality standards, consistent with the Federal CSO Policy and the water quality goals of the Clean Water Act. As a result of this agreement, DEP is targeting to reduce CSOs by 6.32 billion liters per year by 2030.

Delaware Aqueduct Shutdown: DEP has monitored two leaking sections of the Delaware Aqueduct since the early 1990s, which release an estimated 75 million liters per day. The 137-kilometer-long Delaware Aqueduct, the longest tunnel in the world, typically conveys about half of New York City's drinking water each day from reservoirs in the Catskills. To make needed repairs, the aqueduct will need to be temporarily shut down to construct a bypass tunnel that will be connected to structurally sound portions of the existing Delaware Aqueduct to convey water around a leaking section of the tunnel. To offset water demand during this shutdown, DEP has targeted a 75 million liter per day reduction by 2023.

Local Law 172: In 2018, the New York City Council passed Local Law 172 which required the city to produce maps showing areas of the city most vulnerable to increased flooding due to the anticipated effects of climate change, and to publish a long-term plan to prevent or mitigate such increased flooding. Consistent with the Local Law, the 2021 Stormwater Resiliency Plan and maps will be updated at least every four years, and periodically as new modeling is available and as climate change projections are updated.

Policy implications

DEP has spent billions of dollars to create extra capacity through gray and green infrastructure but achieving the goals of a clean harbor and mitigating flooding is becoming more costly and impacting rates, which have increased 50 percent since 2010. While still affordable for most at 0.4 cents per liter, there is a disproportionate impact on low-income communities. This has led to a need for further innovation and promoting projects that offer multiple co-benefits, therefore helping the city to achieve multiple objectives and maximize every dollar of capital funding.

DEP has already established a powerful business case for innovative water technologies, such as green infrastructure and water reuse, by showing that they can help relieve pressure on water systems, reduce combined sewer overflows, save property owners money, and create green jobs. By considering the interconnectedness between all aspects of water management through a One Water approach, DEP is positioned to invest in the future of New York City by promoting affordability, climate resiliency, and sustainability for all its residents.

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9.

Ningbo (China)

A Pilot Project of Smart Water City in Ningbo, China

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Ningbo (China)

Abstract

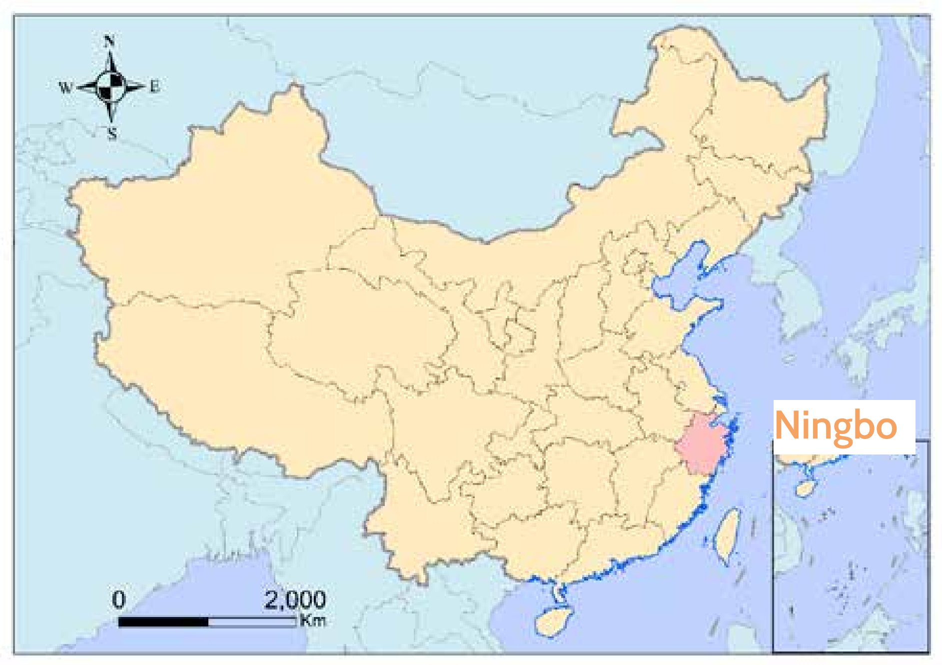
The global water crisis and challenges are well recognized around the world. As a result, there is an urgent need to fight against such mounting water pressures, and smart water technology enables water sector to transit towards a new paradigm that can help to address the degradation of water resources, water ecology, water environment, and water disaster in a coordinated way. Smart water innovation is firmly embedded in the transition of water resources management in Ningbo where lies in the coastal line of the East China's Zhejiang province and is more susceptible to typhoon flooding and coastal flooding. This paper gives a brief and general information on water status, Pilot Project of Smart Water City, and key elements for supporting the implementation of the Project. Although it addresses some challenges, such as it prohibits the progress Ningbo's smart water revolution, the paper also provides four aspects that may help the in a position and profound direction. Ningbo is actively embracing digitalization and intelligence in order to support the effective implementation of transforming and optimizing water, and the city is therefore advancing water security and sustainability in China.

Introduction

Smart water refers to a movement in the water industry involving emerging technology that helps to solve problems through automation, data gathering, and data analysis. Its application in water management potentially provides solutions for leak detection, efficient irrigation, energy efficiency, water quality, water quantity, water quantity, floods and more. The "smart water" has become a promising aspiration and provides a platform for more efficient technology use and more informed decision making (IWRA, 2017).

The development of intelligent technologies is becoming an area of increasing interest and shows a rapid growth in China. It is at the forefront to deal with both the existing and the upcoming urban challenges in many of coastal cities. Its continuous expansion and application provide strong technical support for water management and the smart principles have started integrating into many local, regional, and national strategies. The Ministry of Water Resources of China has paid great attention to the construction and development of a Smart Water City. The Ministry selected 3 pilot Smart Water Cities in March 2020. They include where Ningbo lies in the coastal line of the East China's Zhejiang province and in the South of the Yangtze River Delta (The Ministry of Water Resources, 2020) (see Figure 1).

Figure 1. Ningbo's Location in the Map of China (Source GIWP, 2021)



Ningbo has a territorial land area of 9,816 km^2, a territorial oceanic area of 9,758 km^2, and a total coastline of 1,562 km (OECAN EXPO, 2020). As of 2019, Ningbo has permanent residents of 8.5 million, and is considered to be the most developed economy in China with GDP of 1.2 trillion RMB ($173.69 billion) (The People's Government of Ningbo Municipality, 2020).

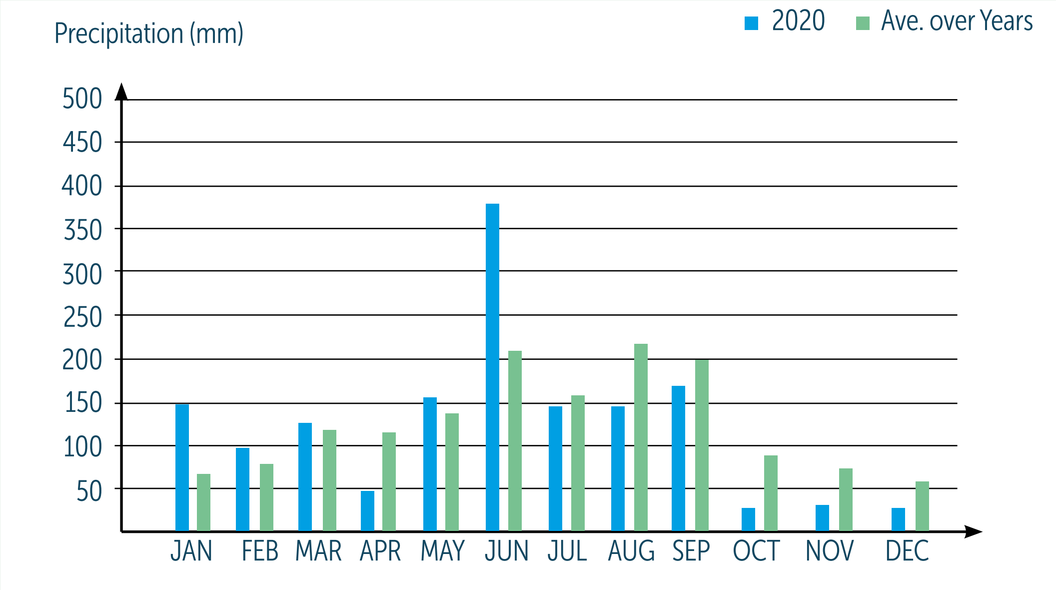
Ningbo is a local commercial center, a hub of a water-transportation network of coastal traffic and canals, and most importantly, it connects to the world as a port city. Among the 102 historical and cultural cities in China, Guangzhou, Quanzhou, and Ningbo are most famous for their deep involvement in the Silk Road on the Sea. There is a record that indicates communication between Ningbo and Japan and Korea and Southeast Asia in past centuries. Thus, Ningbo has been continuously promoting leading enterprises in the marine economic industry which will eventually contribute to the economic and social development of Ningbo (The People's Government of Ningbo Municipality, 2020).

Water status in Ningbo

In 2020, the total amount of water resources in Ningbo is 8.07 billion m^3, the total amount is 41.8% less than 2019 and 3.1% less than the average value. The total water supply is 2.101 billion m^3 including 2.059 billion m^3 of surface water, 41 million m^3 of sewage treatment and rainfall, and 0.1 million m^3 of groundwater. The total water use is 2.101 billion m^3 - an increase of 2.8% than 2019. It consists of 507 million m^3 of domestic water use, 1.536 billion m^3 of industrial water use, and 58 million m^3 of ecological water use, and the water use per capita is 246 m^3. However, the total water consumption[1] contributes to 54.2% (1.139 billion m^3) of the total water use (Ningbo Water Resource Bulletin of Year 2020, 2021).

1. Water consumption is the portion of water use that is lost into the atmosphere through evaporation or incorporated into a product or plant and is no longer available for reuse.

Figure 2. Monthly rainfall in Ningbo (Source Ningbo Water Resource Bulletin of Year 2020, 2021).



Ningbo enjoys a subtropical monsoon climate featuring high relative humidity but distinctive seasons. In 2020, the city receives an average annual rainfall of 1,507 mm but the spatial and temporal distribution of rainfall is extremely uneven (Figure 2), showing the rainfall is more in the North than in the South and is affected by the plum rains of the Asian monsoon in Summer (Ningbo Water Resource Bulletin of Year 2020, 2021).

Because of meteorological and geographical factors, Ningbo often experiences water-related disasters including typhoons, rainstorms, high tides, and floods, with complicated causing factors. Since 1950, there were forty-four typhoons have affected Ningbo, resulting in a total economic loss of more than 93 billion RMB (Tong et al., 2007). From 2000 to 2020, the Emergency Events Database (EM-DAT) reveals that an average of 10 typhoon-related tropical cyclones were registered in China per year, and China's southeast coastal cities (e.g., Ningbo) are more susceptible to typhoons that can lead to severe waterlogging and long-term and large-scale interruptions of traffic and power (Yao, et al., 2021). Also, according to Hanson et al. (2011), Ningbo was ranked one of the top 20 global port cities most prone to flooding risk during the typhoon season when tidal surges and intense rainfall events occur more frequently, and the risk of coastal flooding will rise by 2050 because of population growth, urbanization expansion and land subsidence.

Alongside with the development of the new generation of internet of things, cloud computing, big data, and other cutting-edge technologies, the People's Government of Ningbo Municipality aims to improve the integrated management of water resources and enhance the decision-making ability by addressing innovative smart water technology solutions. The city also strives for preparing prewarning protocols and setting up emergency plans of water crisis, such as storage of disaster relief materials, public promotion of typhoon prevention measures, timely release of early warning information, and relocation from inhospitable and dangerous areas; therefore, the government and the public can be highly aware of water-related disasters and take necessary precautionary actions (Yao, et al., 2021).

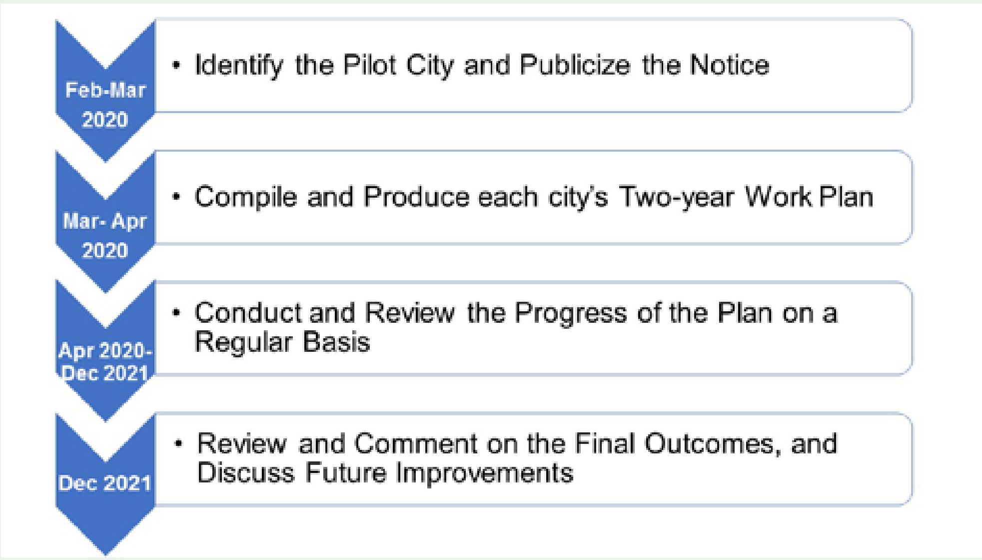
Pilot project of Smart Water City

General background

The rapid growth of smart water is the concrete reflection of invigorating the nation. It is the key approach of achieving the revolution of the water sector and is also the significant indication of high-quality development of water resources. In this context, the Ministry of Water Resources issued the Notice on the Implementation of the Pilot Project of Smart Water Management in March 2020. Shenzhen, Ningbo, and Suzhou were selected as the pilot city to conduct smart water technologies, such as sensors, Internet of things, smart meters, big data, 5G, video monitoring, GIS, remote sensing, satellite mapping, blockchain, and other data sharing tools to steer the development of smart water management that can be implemented to reduce current water management challenges and to strive for urban modernization.

The Notice clearly indicates timeframe and requirement for the pilot project (see Figure 3). It also proposes that as of the end of 2021, these pilot cities should produce cases of excellent application and typical solutions of smart water technologies that can be up-scaled and replicated in a broader range–therefore making continuous breakthroughs, promoting innovative collaboration, and fostering good and healthy growth of the smart water technologies in China (Ningbo Water Resources Bureau, 2020).

Figure 3. Timeframe of the Smart Water Project



Work plan for Ningbo

The project of smart water technology development

The aim of the project is to satisfy the intelligent needs of multidisciplinary fields and levels. It developed an overall framework of "One Cloud, One Network, One Center and Two Platforms" (1+1+1+2) that strives for information services, information security, information sharing, business collaboration, and intelligent application. One Cloud is a cloud platform that helps local government to arrange project-related affairs in a whole picture. One Network means real-time monitoring by developing an Internet of things for water resources. One Center refers to a smart water data center that aims to centralize the data for sharing and research. Two Platforms include an application support platform and an integrated application platform to enhance the analysis ability and refined management (Ningbo Water Resources Bureau, 2020).

The project seeks to make future advancement in the following five aspects: the construction of Internet of Things in water, the construction of data centers and a technical support platform, the construction of an integrated application platform of smart water technology, the construction of basic operation environment system, and the construction of regulatory system. In terms of reinforcement of digitalization, the above aspects have been incorporated and integrated in six key fields: flood and drought disaster prevention, river and lake management, water-related project management, water resources management, hydrological management, and public service. With the assistance of smart water technology, the project was designed to achieve the mechanism of wide consultation, joint contribution, and shared information between Ningbo and its subordinate counties (The Ministry of Water Resources, 2021).

In January 2021, Phase I of the project has officially put into operation. This phase has achieved remarkable results that have been widely recognized by the public and the government. It firstly strengthens the ability of preventing flood and drought disaster. The project has formed one flood risk map of the whole city and built an integrated management platform of flood risk at both the provincial and county level. Phase I effectively improves the real-time flood risk early warning function by simulating the flood process of rivers and develops the early warning function of mountain torrent disaster. Secondly, it enhances the ability of water resources management. The project integrates the data information of 50 reservoirs and 62 water supply plants in Ningbo and constructs an early warning analysis model of the supply and demand between reservoir and water supply plants. The model generates the water allocation scheme within 20 seconds, which can provide scientific support for urban network water supply and cross regional water diversion project. Thirdly, it increases the management ability of rivers and lakes. The project aims to classify the management of rivers and lakes at city, county, and township level, therefore having a holistic grasp the overall situation of rivers and lakes in Ningbo. The project relies on intelligent video analysis technology to carry out intelligent inspection of rivers within 3-5 minutes, and the problem can be automatically alarmed, which greatly improves the efficiency of river inspection. Last but not least, Phase I improves the ability of risk management and control because the information management facilitates the whole life cycle management of water-related projects through the perspective of planning, construction, quality supervision, operation, and safety production. It allows monitoring, review, evaluation, and assessment of the safety risk management and control (Information Center of the Ministry of Water Resources, 2021).

The People's Government of Ningbo Municipality takes Phase I as a good reference, and Phase II will add 400 new basic perception monitoring sites and further explore 10 intelligent smart water technology application scenarios to continuously focus on the key fields of water resources, upgrade the smart water technology, give full play to the project benefits, and strive to produce local, innovative, and emblematic achievements for Ningbo (Hydrological Information Annual Report of Year 2020 in Ningbo, 2021). Ningbo will complete the construction of pilot project of a Smart Water City by the end of December

2021 with high quality standard to achieve the overall goal of "visible, calculable, adjustable, and verifiable" (Information Center of the Ministry of Water Resources, 2021).

Application in key and prior fields

Ningbo is particularly focused on the monitoring, forecasting, and early warning of flood disaster by using the advanced information technology. It reflects the typical needs for Ningbo. Therefore, in Phase I, there are some applications with Ningbo's local characteristics that have been put into real practice.

First, is the application of dynamic flood risk map in water disaster prevention. By using the Internet, big data, cloud computing, and other advanced technologies, and integrating multi-source and multi-scale meteorological forecast results and models, a set of coastal city dynamic flood risk analysis, prediction, and early warning system has been developed. It includes basic information query, real-time flood risk assessment, dynamic flood risk analysis and many other functions. The system can accurately predict the occurrence area, time, and risk level of urban flood disaster 6-12 hours in advance, and therefore, it is responsible for accurate flood forecast, real-time disaster assessment, and rapid decision-making of the whole city.

The second application is the forecast and early warning of mountain torrent disaster. It refers to the real-time monitoring rainfall data and meteorological precise short-term and imminent rainfall forecast data, and combines advanced technologies such as meteorological radar, remote sensing, and dynamic early warning analysis to accurately predict the risk of mountain torrents 1-3 hours in advance. It effectively improves the timeliness and accuracy of mountain torrent early warning. The next step for this application is to add new functional modules such as sending out early warning information based on the big data of real-time population location, dynamic planning of mountain torrent evacuation and transfer route, etc. This application is one of the ten Best Practices that has been recognized by the Ministry of Water Resources.

The last application is the joint water dispatching operation management system of Ningbo's three main rivers (Yong, Fenghua, and Yao). These three rivers have a combined catchment area of approximately 800 km^2. The water resources must be carefully managed at the end of summer to ensure adequate supply for the winter months. Thus, this application uses advanced Internet of Things and automatic control technology, aiming to fulfill centralized monitoring, centralized control, centralized dispatching, and centralized management of water conservation projects alongside these three rivers to ensure the safe and reliable operation of these projects. As a result, it promotes the establishment of integrated management system that includes holistic information control, real-time operation monitoring, and whole process dispatching tracking.

Implementation requirements

Policy support

New water regulations and public policies are emerging worldwide in response to the new normal of a prolonged water crisis and resultant water shortages. Thereby, it is vital to incentivize the process automation and the use of digital technologies to improve water services. China has issued a series of policies to promote the transformation from "digital water" to "smart water ". In 2011, the No.1 document of the Decision on Accelerating the Reform and Development of Water Resources Management by the Communist Party of China Central Committee and the State Council has been announced. In 2015, the State Council has issued the Guidelines on Active Promotion of the "Internet +" Action. In 2016, the Ministry of Water Resources has formulated and published the 13th Five-Year Plan for Water Resources Informatization Development (Yan and Zhang, 2017). In 2020, the Ministry has then decided to issue the Notice on the Implementation of the Pilot Project of Smart Water Management to closely adhere to the governmental instructions. The chosen pilot case should also be problem-oriented and driven by demand. It should take local and regional characteristics and economic development into consideration. Most importantly, excellent cases can provide guidelines and solutions for upscaling applications in other regions in China.

Allocation of responsibility

It is important to create a governance body for the project to delegate the workload. Oversight board is at the top layer of the governance body structure and engages leadership within a project team. The board must discuss the mission, the direction, and the vision for the project and how smart water technologies could fit within and enhance that vision. Identifying priorities, outlining strategies, developing roadmaps, and allocating funding are critical steps in terms of the transition from the "digital" to "smart" era. In tandem, board members alike must then hold each other accountable, ensuring goals are met, resources are allocated, and the mission is fulfilled. The board has its working groups with different working priority. They are responsible for developing roadmaps, accelerating the delivery of the project, working on innovative thoughts with key partners, and ensuring the success of the project.

Communication and coordination

There is a need to strengthen the overall planning and coordination of the pilot project to form an interconnected layout for the whole city. The first is to establish a regular work meeting system. Members of the communication group or liaison officers of difference departments will attend the meeting. They shall have the opportunity to timely raise and solve problems encountered in the work. The second is to establish a top-down notification system. The city will regularly review and report the progress and operation of the pilot project, as well as oversee the implementation of the pilot project as planned.

Capacity building

First, we need to ensure funding sources. The pilot project can be viewed as a valuable opportunity to actively connect with major bureaus, such as Ningbo Municipal Bureau of Water Resources, Ningbo Municipal Bureau of Development and Reform, etc., and to increase the guaranteed level of smart water funds. Second, technical support should be ensured. Ningbo needs to produce corresponding norms for technical requirements, data resources, operation services, geographic information, etc., and they shall be fully implemented in construction and operation. Third, we should strengthen the publicity and interpretation of the relevant policies, regulations, and programs of smart water, so as to unify the understanding of the purpose, significance, and importance of the pilot project, and to fully mobilize the subjective initiative of the relevant personnel. Lastly, we should carry out the relevant technical training to improve the professional ability and technical skill, thus the project can come into effect smoothly and effectively.

Conclusions

To continuously raise the importance and prominence of smart water technology on flood and drought disaster prevention of pilot project phase I in Ningbo, Ningbo should continuously improve the following four aspects in a position and profound direction.

First is the overall strategic arrangement, including the arrangement for data resources, technical applications, and many other perspectives of Ningbo smart water projects. Second is the real-time online monitoring to improve the ability of information capture and perception. Third is the water resources data sharing. With the assistance of cloud computing, artificial intelligence, and other technologies, Ningbo smart water resources data center has been constructed and it can help to collect countless data, centralized sharing, and further explore the uses of the data. Lastly is the support of platforms that can take real applications as basic demand and enhance the analysis ability and refined management.

While the adoption of smart water solutions will seldom be a smooth journey, it contains many hurdles and barriers that slow, and at worst, prohibits the progress of pilot project. To comprehensively fulfil the requirements of smart water revolution, regulatory, technology, and organizational challenges must be addressed. First, there is a growing challenge of systems integration and interoperability. Second, the people play a key role in smart water transition; this relates to skill gaps, workforce transition, and change management. Third, with limited budgets, financing solutions without a clear value proposition can often pose a tough decision to whether deploy a smart water solution that can drive long-term efficiencies or not. Finally, continual advancements in smart water need to ensure cyber-security and customer data protection.

To fight against mounting global changes, the dawn of the smart water technology has demonstrated efficiency in mitigating pressures of scarcer and less reliable water resources, it is gaining momentum and becomes increasingly necessary to provide more reliable, qualified and secure water resources. Thus, by transiting towards a new paradigm for urban water management, we can help create a more sustainable world.

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