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Integrative Review of Decentralized and Local Water Management Concepts as Part of Smart Cities (LoWaSmart)

Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

An evidence-based assessment of decentralized and local water management concepts and how they relate to smart city concepts is presented. Decentralized water management is based on the principle of integrated water cycle management and water-sensitive urban design. A “smart city” is generally defined as a city seeking to address public issues via information and communication technology (ICT)-based solutions on the basis of a multi-stakeholder, municipally based partnership. Using evidence-based review principles it is shown that when ICT is applied to water management in cities, it enables the collection of data for better understanding of how a city functions and to improve it to the benefits of its inhabitants and the environment.

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1. Lokal vannforvaltning	1. Local Water Management
2. Desentral vannforvaltning	2. Decentralized Water Management
3. Smart Cities	3. Smart Cities
4. Evidens basert kunnskapsoppsummering	4. Evidence based reviews

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Integrative Review of Decentralized and Local Water Management Concepts as Part of Smart Cities (LoWaSmart)

A systematic evidence-based review

Preface

The knowledge is increasing rapidly worldwide. This brings about difficulties to identify and compile the state of research and technology. Especially for questions which are relevant for the further development of society and which are associated with high costs it is important to obtain a good and substantial overview about the state of knowledge and to make sure that this is based on knowledge which is generally approved, rather than just statements or opinions. Thus, there is a need for rigor, objectivity and transparency in reaching conclusions from a huge body of scientific information.

The methodology of evidence synthesis to produce systematic reviews is used widely today in sectors of society where science can inform decision making. It has become a recognized standard for accessing, appraising and synthesizing scientific information.

The report presented here is the result of a short and quick evidence synthesis review towards the questions, to which extent local and decentralized water management in urban areas is beneficial generally or under certain circumstances and to what extent it relates to smart city infrastructures.

In that context the review nicely demonstrates that systematic evidence-based review principles are very useful for gathering evidence even with limited resources.

Oslo, 30.06.2016

Wolfgang Uhl

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1. Sammendrag

Denne rapporten gir en evidensbasert vurdering av desentraliserte og lokale vannforvaltningskonsepter, og hvordan dette relaterer seg til fremtidens Smart Cities. Vurderingen ble påbegynt i henhold til prinsippene for evidensbaserte vurderinger. Først ble rundt 3400 dokumenter gjennomgått. Disse ble redusert til ca. 50 dokumenter som ble studert i detalj og brukt i denne rapporten.

Desentralisert vannforvaltning er basert på prinsippet om integrert vannsyklusforvaltning og vannsensitive urbane design. Kloakk og overvann anses som en ressurs i stedet for avfall som slippes ut, intelligent vann- og ressursgjenbruk, og er avhengig av å samle opp vann i stedet for å la det strømme gjennom rørene utover i resipienten. Slike systemer gir betraktelig mer fleksibilitet.

Smart City er generelt definert som en by som søker å løse offentlige problemstillinger via Informasjons- og kommunikasjonsteknologi (IKT)-baserte løsninger på grunnlag av et kommunalt samarbeid med flere interessenter. Når man undersøker byene som kalles "smart cities" i henhold til smart-city kriteriene, er det ofte uklart hvorfor enkelte byer kaller seg "smart".

Generelt er det bevist at når IKT tas i bruk innen vannforvaltning i byer, muliggjør det innsamling av data, for å bedre kunne overvåke og administrere vannkvalitet, forbruk og lekkasjer. Aktivering av teknologi for å kunne kommunisere og for å bli multifunksjonell (kobling med andre Smart City-elementer) genererer data for å bedre forstå hvordan en by fungerer, samt å kunne bruke denne kunnskapen til å forbedre byen til fordel for innbyggerne og miljøet.

Denne vurderingen viser at evidensbaserte vurderingsprinsipper er svært nyttige for å samle bevis selv med begrensede ressurser.

2. Summary

This report provides an evidence-based assessment of decentralized and local water management concepts and how these concepts relate to the smart cities of the future. The review began according to the principles of evidence-based reviews, in that at first, about 3400 documents were checked, which were condensed to about 50 to be studied in detail and used for this report.

Decentralized water management is based on the principle of integrated water cycle management and water-sensitive urban design. It considers sewage and storm water as resources rather than waste to be discharged, intelligent water and resource reuse, and relies on capturing the water rather than letting it flow through the pipes into the receiving waters. Such systems extend flexibility considerably.

A “smart city” is generally defined as a city seeking to address public issues via information and communication technology (ICT)-based solutions on the basis of a multi-stakeholder, municipally based partnership. However, when checking cities that are named “smart cities” according to smart city criteria, it is often unclear why a certain city calls itself “smart”.

Generally, there is evidence that when ICT is applied to water management in cities, it enables the collection of data in order to better monitor and manage water quality, usage and leakages. Enabling technology to communicate and become multifunctional (linking with other smart city elements) generates data to enable better understanding of how a city functions and use of that knowledge to improve the city to the benefits of its inhabitants and the environment.

This review demonstrates that systematic evidence-based review principles are very useful for gathering evidence even with limited resources.

3. List of Abbreviations

DMA	district metering area
GHG	greenhouse gas
ICT	information and communication technology
ITU	International Telecommunication Union
NRW	non-revenue water
OECD	Organization for Economic Co-operation and Development
MNF	minimum night flow
SWM	smart water management
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
WBKMS	web-based knowledge management system
WSUD	water-sensitive urban design

4. Evidence-based reviews and approach of this study

Systematic evidence-based reviews enable the establishment of what is known from research and what is not known and combines discussions about the evidence required and technical tasks to find and describe the evidence available. The basic procedure that an evidence-based review follows is given below in Figure 1 (Gough et al., 2013).

Figure 1: Procedures and principles of an evidence-based review.

In this review, we provide an evidence-based assessment of decentralized and local water management concepts and how these concepts relate to the smart cities of the future. The literature review began with a search of different keywords such as "smart cities", "smart water management and solutions", "urban drainage" and "centralized/decentralized and local water and wastewater management". For that, different scientific databases such as ScienceDirect, Scopus, Google Scholar, ResearcherID and ResearchGate as well as web pages from different national and international organizations were used.

As shown in Figure 2, out of the total number of about 3400 documents containing the search keywords, during the progress of the evidence-based review, the number studied more closely decreased with the increasing level of evaluation. Finally, a total of 126 documents, including scientific papers, book chapters, reports, theses and web pages, were selected for reading. Finally, out of those, 56 documents were chosen for this evidence-based review.

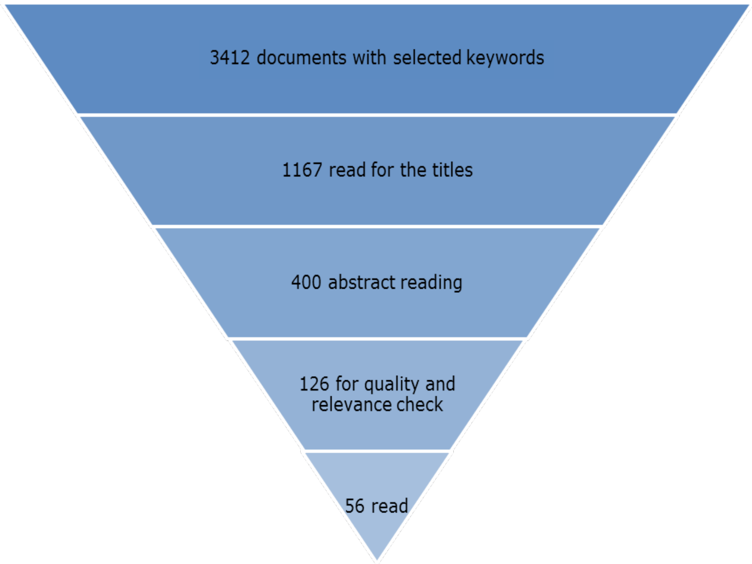

Figure 2: Approach to literature review.

5. Defining the review questions

One of a city's most important pieces of critical infrastructure is its water system. With the increasing growth and concentration of the world population in urban centres (UN, 2010), it is inevitable that water consumption will grow as well. Water management is an integral part of the urban system, impacting on each pillar of the urban society and its functionality, sustaining populations, generating energy, supporting tourism and recreational activities, ensuring environmental and human health, and driving local economic development (ITU, 2014). Considering more than half of the world's population currently live in urban areas, which is projected to increase to 70% in 2050 (UNDESA, 2014), the cities of the future need a water distribution and drainage system that is sound and viable in the long term to maintain growth and should have the capacity for monitoring and networking with other critical systems to obtain sophisticated information on how they are performing and affecting each other (Leinmiller and O'Mara, 2016).

The questions defined in this review are: (1) what are the prospects and constraints of decentralized and local water management systems and technologies?; and (2) what is their potential for integration into the smart cities concept.

6. Definition of smart cities

The concept of smart cities is not static and "there is no absolute definition of a smart city, no end point, but rather a process, or series of steps, by which cities become more 'liveable' and resilient and, hence, able to respond quicker to new challenges" (DBIS, 2013). The "Mapping Smart Cities in the EU" report states that "A smart City is a city seeking to address public issues via Information and Communication Technology (ICT)-based solutions on the basis of a multi-stakeholder, municipally based partnership" (Manville et al., 2014). The report suggests that "A smart city is quintessentially enabled by the use of technologies (especially ICT) to improve competitiveness and ensure a more sustainable future by symbiotic linkage of networks of people, businesses, technologies, infrastructures, consumption, energy and spaces".

In Europe, the "smart city" has quasi-official status, with the European Parliament ranking cities in 28 nations based on performance in governance, human flourishing, livability, mobility, economy and the environment (Manville et al., 2014). It is proposed that a smart city has six characteristics, which are given in Figure 3.

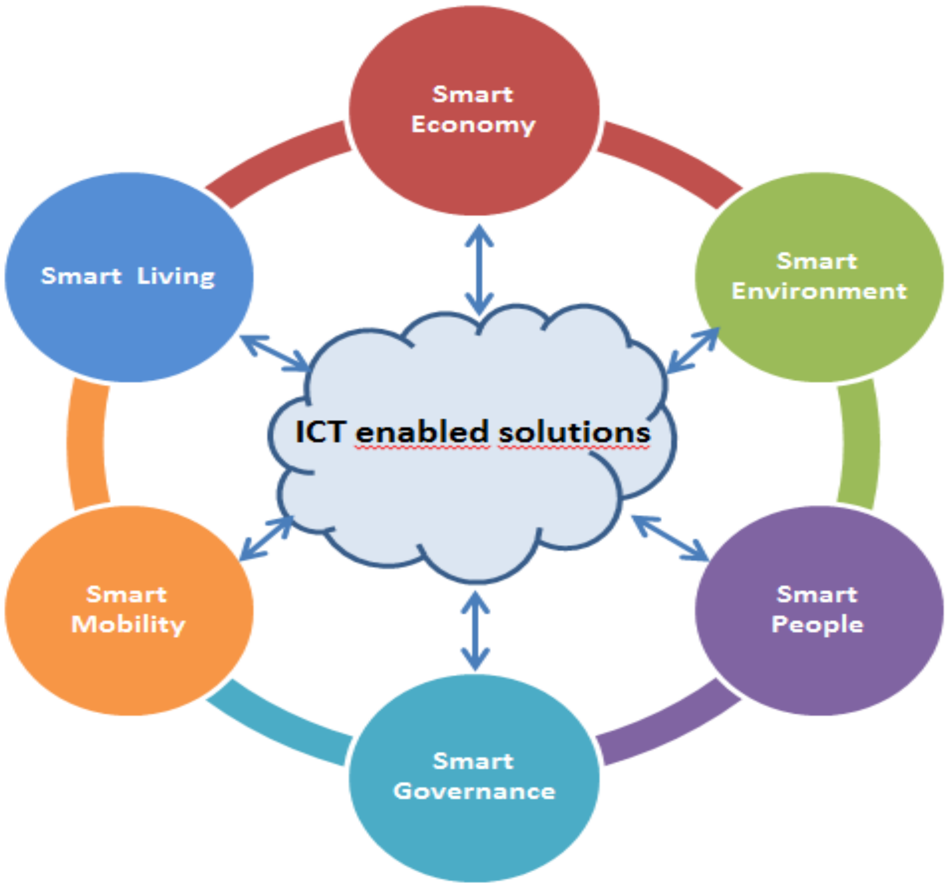

Figure 3: Characteristics of a smart city.

Each of the components is defined in the EU report on "Mapping Smart Cities in the EU". According to the report, smart governance is "joined up within-city and across-city governance, including services and interactions which link and, where relevant, integrate public, private, civil and European Community organizations so the city can function efficiently and effectively as one organism". Smart economy refers to "e-business and e-commerce, increased productivity, ICT-enabled and advanced manufacturing and delivery of services, ICT-enabled innovation, as well as new products, new services and business models". Smart mobility covers "ICT supported and integrated transport and logistics systems". Smart environment "includes smart energy including renewables, ICT enabled energy grids, metering, pollution control and monitoring, renovation of buildings and amenities, green buildings, green urban planning, as well as resource use efficiency, reuse and resource substitution which serves the above goals". Smart people are those with "e-skills, working in ICT-enabled working, having access to education and training, human resources and capacity management, within an inclusive society that improves creativity and fosters innovation". Smart living means "ICT-enabled lifestyles, behaviour and consumption".

7. Centralized vs decentralized water systems

7.1 Development of centralized water systems

Centralized systems were developed in the middle of the nineteenth century in response to tackling the outbreaks of cholera, typhus and other fatal diseases that occurred in the major cities of Central Europe and the USA. The solution to the problem was the continuation of public sewer systems for wastewater collection and transportation, which resulted in wastewater being directed out of the cities to the nearest waterway where self-purification could take place. As a result, outbreaks of cholera and typhus were reduced initially and then completely prevented. The first comprehensive sewer network was built in Hamburg in 1842 and was soon followed by other cities (Hophmayer-Tokich, 2006). Over time, the self-purification capacity of the receiving water body was exceeded and as a result the water quality gradually deteriorated, which led to the development of technologies for the treatment of water before discharge into the environment.

The main features of decentralized and centralized water management are given in Table 1.

Table 1: Main features of centralized and decentralized water management (Domènech et al., 2011)

Factor	Centralized water management	Decentralized water management
Scale	Large-scale systems	Small-scale systems
Types of water sources	Distant and local water sources	Local water sources
Governance	Top-down governance model	Multilevel governance model
Participation	Limited public participation in water management	Active public participation in water management
Awareness	Citizens are alienated from the water cycle	Citizens are more aware of the water cycle
Cost sharing	Highly subsidized	Full cost recovery
Water quality	Very high water quality for all uses	Different water qualities and fit-for-purpose water use
Environmental impacts	Environmental impacts are significant	Environmental impacts are reduced
Resilience capacity	Limited capacity to adapt to extreme situations	Enhanced capacity to adapt to different situations

7.2 Advantages and disadvantages of centralized systems

Centralized water systems have, in general, ensured adequate water supply, sanitation and drainage services in cities around the world (Sitzenfrei et al., 2013). However, several factors such as climate change, demographic changes, socio-economic factors, the urge for biodiversity, energy use, water supply and consumption, as well as ageing water and wastewater infrastructures, pose challenges to scientists, managers and policymakers alike (Sharma et al., 2010). Only a small portion of the high-quality potable water provided by the centralized systems is actually used for potable purposes and most of the fraction of the potable water is used for applications that have relatively low water quality requirements such as toilet flushing and garden irrigation. Moreover, all wastewater streams are mixed with human waste in sewers prior to treatment and discharge. The increasing growth and concentration of the world population in urban centres has resulted in stresses on the freshwater resources through overextraction and the discharge of urban pollution into waterways (UNEP, 2008). Under such conditions, the centralized water service model with the bulk transfer of fresh water and the bulk disposal of wastewater is not always the most sustainable solution for urban development (van Roon, 2007).

The little flexibility offered by the centralized drinking water systems causes an imbalance between supply and demand (Leirens et al., 2010). Similarly, for the wastewater treatment systems, when the inlet wastewater flow rate is higher than the plant capacity, the system becomes insufficient, and conversely in the case of a low inlet wastewater flow rate, the treatment systems also become infeasible, as a consequence of fixed treatment processes (Lee et al., 2015). Significant focus is currently placed on the paradigm shift in urban water and wastewater – away from the decaying centralized systems towards decentralized ones (Ødegaard, 2012) to maximize the use and recovery of water, energy, nutrients and materials (Ma et al., 2015).

7.3 Advantages and disadvantages of decentralized systems

Decentralized water management is a concept in which water is managed, collected, treated and disposed/reused near or at the point of generation (Crites and Tchobanoglous, 1998). With the increasing awareness of the value of closing the loop on urban water flows, decentralized systems are often considered to be implemented for the dual purpose of reducing flows to centralized wastewater treatment systems and providing opportunities for the reuse and recycling of wastewater at the local level on a fit-for-purpose basis, such as reuse of treated grey water for toilet flushing and irrigation (Diaper et al., 2007). Decentralized systems are therefore perceived as an alternative approach to centralized systems in providing water, wastewater and storm water services as part of the integrated urban water management and water-sensitive urban design (WSUD) (discussed in detail in Section 4.2) concepts, which are increasingly considered in the planning and design of urban water management (Sharma et al., 2010). Figure 4 provides an example of the decentralized systems for reuse of grey water and energy recovery.

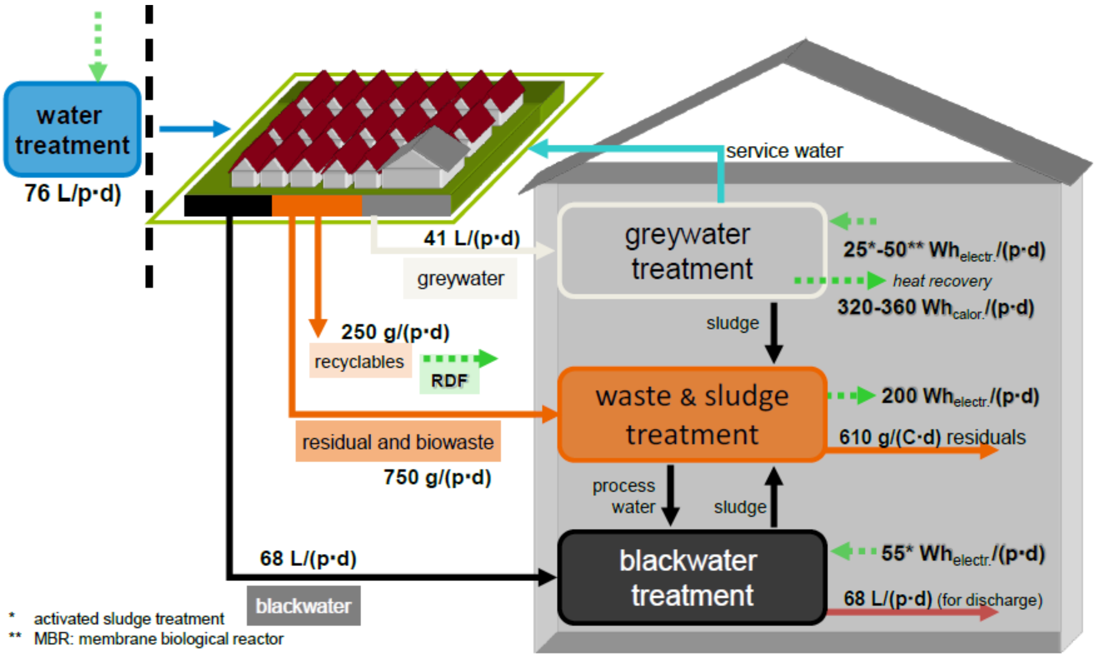

Figure 4: Integrated urban water management using decentralized management (Bieker et al., 2010).

By reducing capacity constraints, decentralized systems provide a cost-effective solution to avoid or defer investment in centralized urban water infrastructure (Mitchell, 2006). ICT provides opportunities for improving the productivity and efficiency within the water sector by providing reliable data about water resources management, development, usage and demand. It allows continuous monitoring of water resources, providing real-time monitoring, making improvements in modelling and problem diagnosis, and thus enabling proper maintenance and optimization of all aspects of the water network. The increasing availability of more intelligent, ICT-enabled means for managing and protecting water resources has resulted in the development of smart water management (SWM). SWM promotes sustainable consumption of water resources through co-ordinated water management, by integrating ICT products, solutions and systems, to maximize the socio-economic welfare of a society without compromising the environment. SWM can be applied to multiple sectors (e.g. industries, agriculture) and urban environments. In cities, SWM strives to achieve three main goals through the utilization of ICTs, namely: (a) co-ordinated water resource management and distribution, (b) enhanced environmental protection, and (c) sustainable provision of public services and economic efforts (ITU, 2014).

8. Smart water solutions as a prerequisite for decentralized water management in smart cities

8.1 Smart water solutions

The term "smart water" refers to water and wastewater infrastructure that ensures that water and the energy used to transport water is managed efficiently (Leinmiller and O'Mara, 2016). SWM in cities addresses the challenges in the urban water management and water sector through the integration of ICT products, solutions and systems in areas of water management and sanitation (ITU, 2014). A smart water system gathers meaningful and actionable data on the flow, pressure and distribution of a city's water. It enables continuous monitoring of the water resources and identification of problems in the urban water sector, allowing maintenance issues to be prioritized and managed more effectively, as well as data to be gathered that are needed to optimize all aspects of a city's water management system and information fed back to the citizens, water operators and technical services of cities.

The Organization for Economic Co-operation and Development (OECD) report "Water Security for Better Lives" suggests that achieving water security objectives means maintaining acceptable levels for four water risks: risk of shortage (including droughts), risk of inadequate quality, risk of excess (including floods) and risk of undermining the resilience of freshwater systems (e.g. by exceeding the coping capacity of the surface and groundwater bodies) (OECD, 2015). This approach evidences an increasing awareness of the importance of tackling water-related challenges from an integrated, holistic perspective, considering both acceptable levels of risks and their potential consequences (economic, environmental, social) for urban stakeholders (ITU, 2014). Smart water systems have "a high degree of automation, rapid response times or the capability to capture information in real time, the ability to transmit data between remote locations and the data processing facility, and for the data to be interpreted and presented to utilities and end-users" (OECD, 2013). Implementation of smart and integrated concepts to manage water and wastewater systems offers the possibilities of local recovery of water, nutrients and energy from wastewater streams, leading to more ecologically sound and potentially economically beneficial water, storm water and wastewater management (Mitchell, 2006). An example showing some of the benefits of the implementation of smart and integrated water strategies is Copenhagen harbour, where sewage overflows are measured by an integrated bathing water forecast system and an automatic warning system identifies whether it is safe to swim: the system informs in real time if the water quality is in compliance with the EU bathing water directive. The harbour is now an attractive recreational and swimming spot. This real-time system is also applied for other beach areas in Denmark as well as in some of the most popular beaches in Sweden (The-Rethink-Water-Network, 2013a).
Reducing energy consumption and vulnerability to climate change is a critical component of any water systems, and decentralized systems provide an opportunity to achieve these objectives. Combined treatment of grey water and storm water can employ less energy-intensive technology and with lower capital expenditure. Using this reclaimed water for non-potable applications such as laundry could also significantly reduce the burden on the local municipality. The introduction of regulations can facilitate such scenarios. Copenhagen has introduced new planning regulations that require new developments to implement a three-tiered system: one for rainwater, one for storm water and one for black wastewater.

When making a comparison between grey-water decentralized and centralized reuse systems, Matos et al. (2014) showed that decentralized reuse systems consumed less energy and produced less CO_2 than centralized systems. Although these findings demonstrate the importance of decentralized grey-water reuse, they cannot be considered representative of the energy requirements and levels of CO_2 emissions. A significant knowledge gap therefore exists with respect to energy demands and CO_2 emissions. The economic feasibility of decentralized systems, however, is anticipated to be greater than that of centralized systems if the long-term operational, environmental and social benefits of each system are taken into account.

8.2 Water-sensitive urban design (WSUD) in smart cities

Traditionally, water has often been considered as an afterthought once development plans have progressed to detailed design (SuDS-Wales, 2012). Water has been considered an "engineering-only" design element with little input from those who shape the form and function of urban places. The engineering of water management has also been historically isolated, with one engineer designing the drainage system, another carrying out flood-risk assessment, another looking at water supply and wastewater management, and the building engineers separately looking into meeting water-use-reduction targets on a building-by-building basis. Water-sensitive urban design (WSUD) is an approach to integrate the urban water cycle into urban planning and design and mitigate urban impacts on waterways (ACT, 2014).

WSUD is based on several key principles (Wong, 2006):

- "Reducing potable water demand through water efficient appliances and seeking alternative sources of water such as rainwater and (treated) wastewater reuse, guided by the principle of 'fit-for-purpose' matching of water quality and end uses
- Minimizing wastewater generation and treatment of wastewater to a quality suitable for effluent reuse opportunities and/or release to receiving waters
- Treating urban stormwater to meet water quality objectives for reuse and/or discharge to surface waters
- Using stormwater in the urban landscape to maximize the visual and recreational amenity of developments"

Figure 5 below illustrates how the water cycle works in natural and urban areas and how WSUD can lead to the achievement of a more natural hydrologic regime.

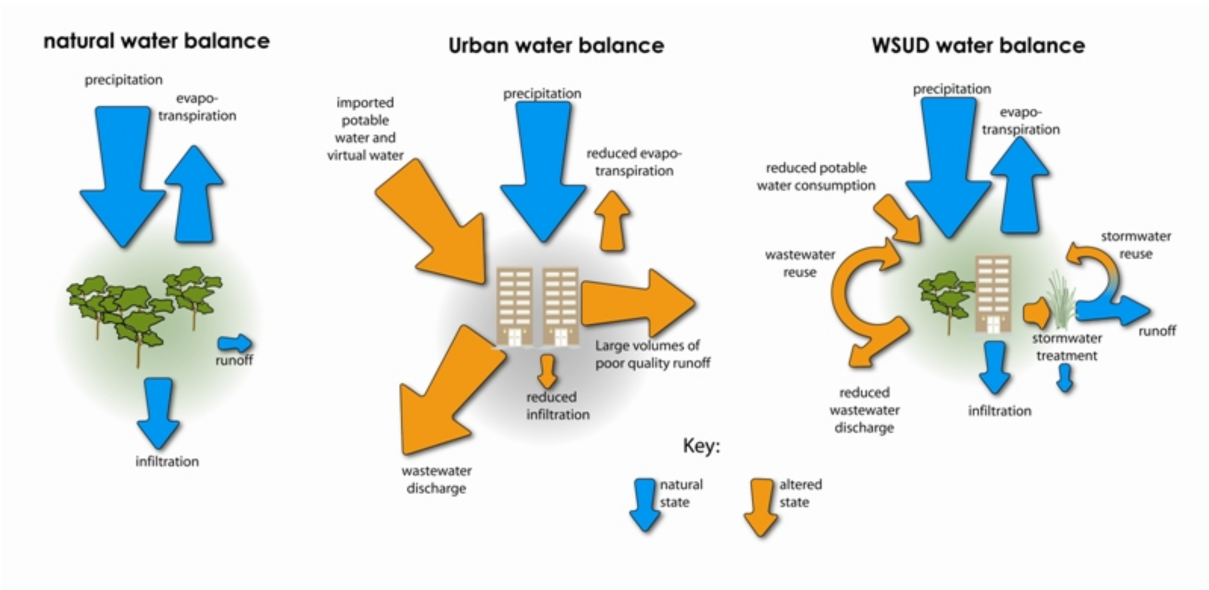

Figure 5: WSUD in relation to natural and typical urban water balance (Source: National Water Commission, Australia).

Adapting to a changing climate poses challenges but at the same time presents an opportunity to rethink urban development and gain greater value from investments. Incorporation of various WSUD elements can contribute to greener and more pleasant urban areas leading to reduced CO_2 emissions and at the same time extending added benefits such as increased real estate values, increased biodiversity and more recreational opportunities (State-of-Green 2015), as evidenced by the Copenhagen harbour project mentioned earlier.

8.3 Smart metering and smart non-revenue water (NRW) management

How various elements of decentralized smart water systems fit in the overall water management system of a smart city and contribute to the productivity of water use and system efficiency in urban water systems is being increasingly documented in the literature. Smart metering and smart water grids as essential components of smart water systems are discussed here with specific case studies and, where available, a reference to Norway is made to emphasize the value of these critical smart water components.

Conventional centralized water networks (Newbold, 2009) involve the transportation of water from a single or few entry points to the entire urban area. These systems are susceptible to leakages and pipe bursts along the transportation lines (Olsson, 2011). In fact, leakages and pipe bursts are frequent in urban water distribution networks, which in cases of major pipe bursts can lead to a complete shutdown of the water distribution system (Misiunas et al., 2005).

Non-revenue water (NRW) represents the difference between the volume of water that is put into a water distribution system and the volume that is billed to customers (ADB, 2010), i.e., lost during transportation due to leackages. Incorporating smart water approaches allows NRW to be minimized by finding leaks quickly and even predictively using real-time data and comparing that to model network simulations. This can also allow municipalities to recover costs incurred in treatment and pumping. It has been demonstrated that a 25% loss, which is not an unusual amount, of produced water for a medium-sized city (population of 100,000–500,000) with almost 400,000 m^3 per day of produced water incurs over $13 million per annum in non-recoverable labour, chemical and energy expenses (Leinmiller and O'Mara, 2016).

NRW is one of the most important performance indicators for a water utility, and to achieve a reliable picture, precise metering equipment is needed both at the pumping inlet and at the customer level (The-Rethink-Water-Network, 2013b) to benefit water utilities and policy makers alike (Stewart, 2011). Conventional network leakage monitoring in district metering areas (DMAs) is done by measuring the minimum night flow (MNF) at designated time intervals; a leak is suspected when the MNF exceeds a predetermined threshold, which is expensive in terms of time to locate and labour to repair (Hunaidi and Wang, 2006).

Smart meters store and transmit measurements at frequent intervals and play a crucial role in the collection of a registry of end-use water consumption data (Willis et al., 2013), including the leaks associated with existing homes/dwellings (Stewart, 2011). Smart metering couples two distinct components to collect disaggregated water consumption data: advanced meters that capture water use data, and a communication system that captures and transmits usage information in real, or almost real, time intervals (NYSERDA, 2003). Figure 6 shows an example of automated and smart metering infrastructure and SWM capabilities.

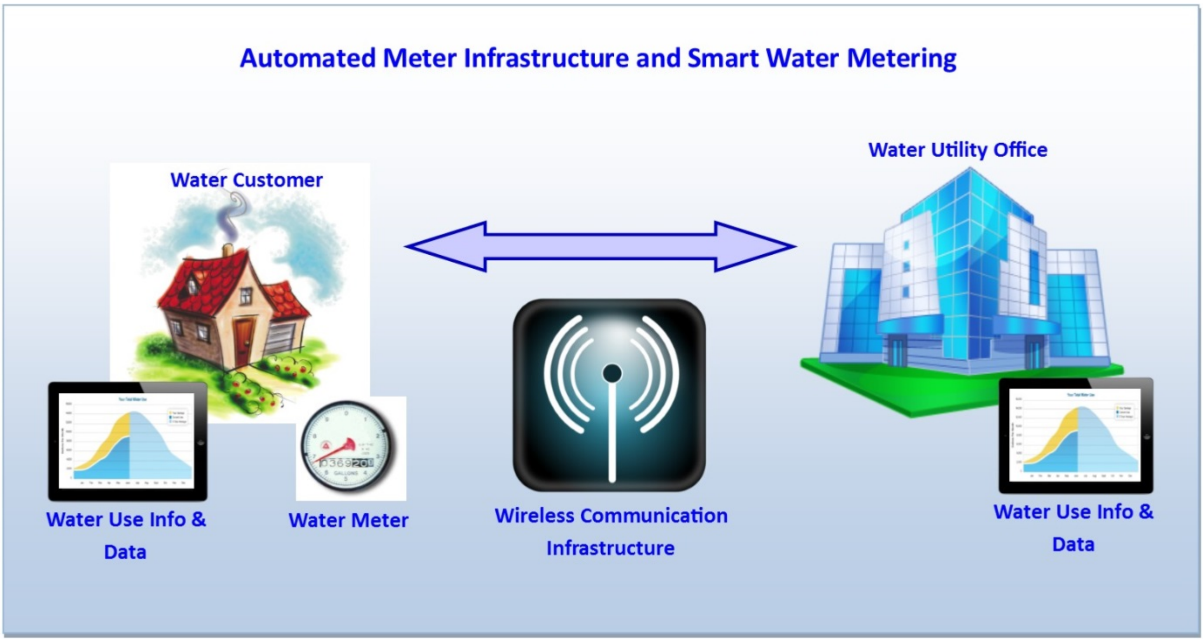

Figure 6: Automated and smart metering infrastructure (Source: Alliance for Water Efficiency (2016)).

Smart meters perform three core functions: (1) automatic and electronic data recording, (2) data collection, and (3) communication of water usage data (Idris, 2006). A smart meter has a high-resolution water meter linked to a data logger to capture water-use data that can be downloaded as an electronic signal and analysed using available technology (Stewart et al., 2010). The electronic signals from smart meters can also be transferred to computers or central data hubs via data distribution technologies such as the GSM network (Hauber-Davis and Idris, 2006).

Smart NRW management is based on the principle of breaking the distribution system down into smaller, more manageable units, i.e., DMAs. A typical DMA layout is given in Fig. 7.

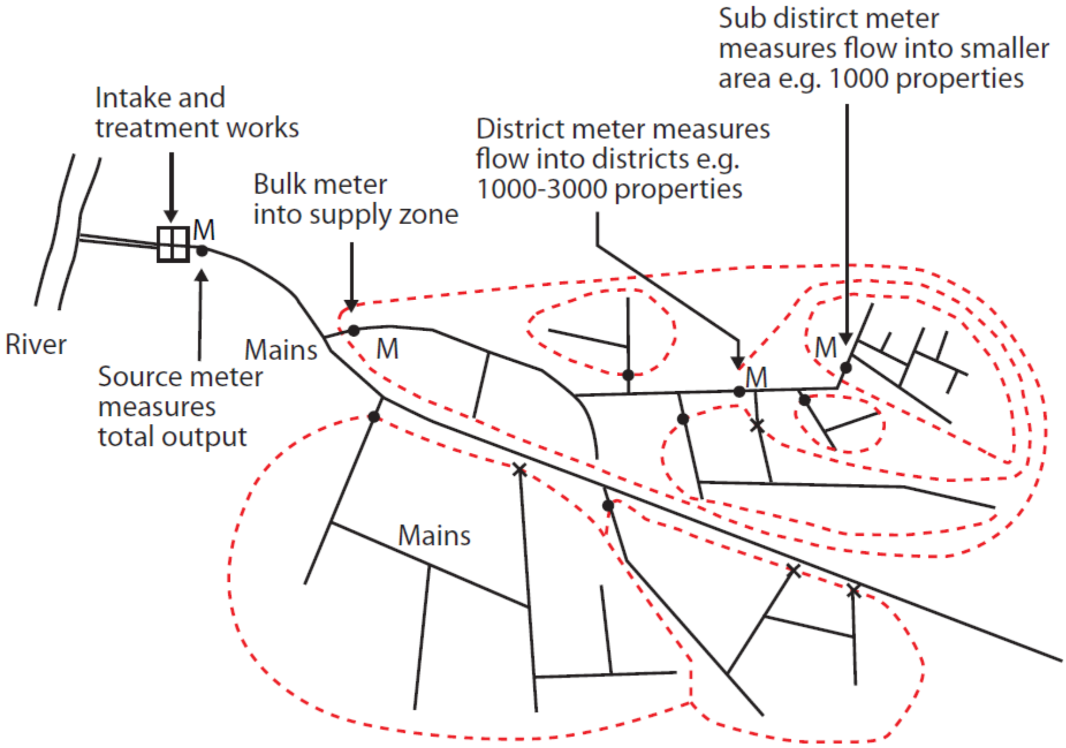

Figure 7: Typical DMA layout (adapted from Farley et al. (2008)).

The optimal number and design of these areas can be determined by hydraulic modelling and the data produced from the DMAs can be used by the utilities for better decision-making. The system can be further developed by building in a more advanced online system of monitoring and real-time control for the whole distribution system. In Denmark, cost-effective leakage monitoring technologies and management systems have led to a significant reduction in leakage to as low as 5% in some big cities despite very old piping networks (The-Rethink-Water-Network, 2013b). Information about the distribution system and the better management of the system makes prioritizing actions easier to achieve the NRW reduction targets successfully. The extent to which such solutions are practical in other cities will depend on the nature of the distribution infrastructure, and collecting more information using the necessary tools such as GIS and SCADA is critical.

A very important consideration when controlling leakage is that the motive is not only the leakage itself but other factors such as water quality and the amount of leakage are important considerations in deciding on the best approach to fix the leakage (Venkatesh, 2012). Some leakages are not fixed due to cost considerations in centralized systems. Incorporating smart water components (smart water metering) can enable better identification of the leakage point at a much lower cost than in centralized systems. Further work, however, is needed to provide evidence on how decentralized systems could contribute to reducing costs of leakage as well as better identifying the leakage points in the distribution system.

A comprehensive web-based knowledge management system (WBKMS) that integrates smart metering, end-use water consumption data, wireless communication networks and advanced information systems has been proposed to provide real-time data to both water corporations and consumers to enhance their current level of understanding of how, when and where water is being consumed (Stewart et al., 2009). By adopting high-resolution water meters (72.5 pulses per litre) and data loggers recording data at 10-second intervals for 200 homes, valuable data were generated to examine the feasibility of developing a robust system for providing real-time high-resolution end-use data to both water managers and consumers.

The proposed WBKMS enables the empowerment of individuals by providing them with instant intelligent information, which has implications such as informing users of daily/monthly water use, regulating water use, leak identification, water infrastructure planning and automated billing.

9. Norwegian examples and developments

9.1 Smart cities in Norway

A smart environment is the most popular characteristic among EU smart cities, including Nordic member states (Manville et al., 2014), but smart water management is rather less focused in Norway and several other EU member states. In Norway, significant focus has been placed on clean-energy initiatives. Some of the initiatives taken in smart cities in Norway and the extent to which they include smart water elements are presented in the following.

Smart cities in Norway include Oslo, Bergen, Trondheim and Bærum. It is, however, not very clear what makes these cities smart compared with other cities and what criteria are considered in classifying these cities as smart cities. Energy efficiency is one of the focus areas of Norwegian smart cities. For example, in the ECO-city project started in 2005 in Trondheim, one of the measures in the plan was that the energy standards for all new municipal buildings are to be at least 25% better than the national standards (SCIS, 2015).

There are several examples of integration of one or in some cases more smart water elements in what we define here as "smart neighbourhoods". One such successful example is in Klosterenga, Oslo, in which grey water is treated in an advanced nature-based grey-water treatment system in the courtyard of the building (Figure 8). The system consists of a septic tank, pumping to a vertical downflow single-pass aerobic biofilter followed by a subsurface horizontal-flow porous media filter. It serves 100 people in 33 apartments. For nitrogen, the effluent has consistently been below the WHO drinking water requirement of 10 mg/L and no faecal coliforms have been detected after the treatment. The system is compact with 1 m^2/person of space needed; part of the treatment area is also used as a playground (Jenssen, 2005). Although the system does not reuse the treated grey water, future systems could be designed for purposes such as toilet flushing and garden irrigation. The feasibility of such decentralized systems in Oslo as well as other cities could be a great starting point considering the relatively recent interest in grey-water recycling in Norway.

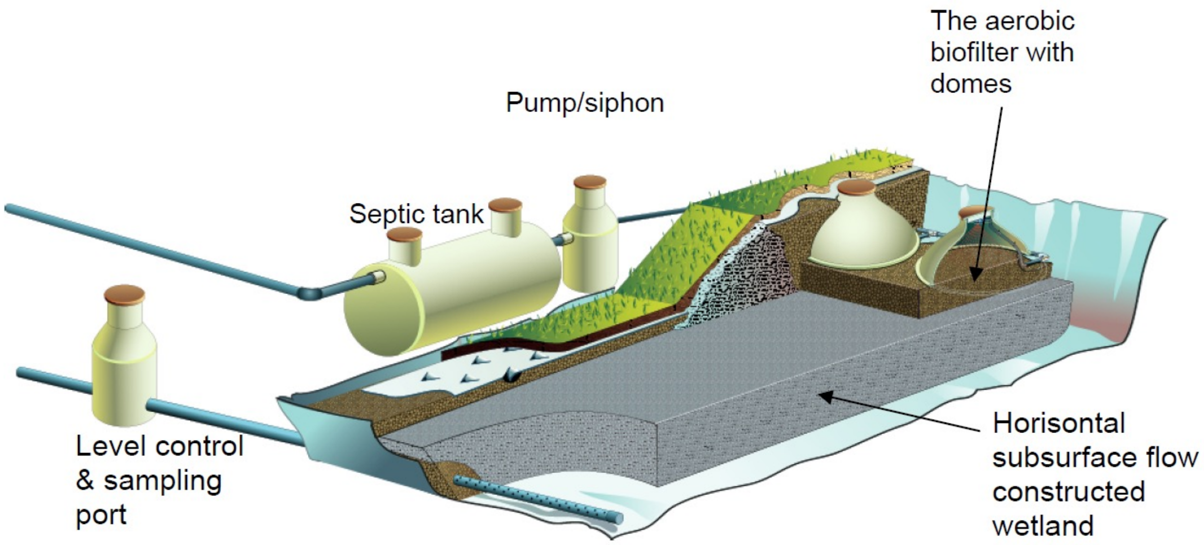

Figure 8: Grey-water treatment in an advanced nature-based grey-water treatment system in Klosterenga, Oslo (adapted from Jenssen, 2005).

Bergen is one of the first smart cities in the world and has the long-term goal of becoming a carbon-neutral city. Like many other cities, Bergen has a combined system for the transport of wastewater and surface water. Addressing the risk associated with increased rainfall (in quantity and intensity) in terms of the capacity of both the network of sewers and the treatment plants has been prioritized by the City of Bergen in its list of prioritized projects (City of Bergen, 2008). The separation of the sewage and surface water is a priority along with modelling the whole sewerage network with a view to identifying both critical points and areas where it is possible to establish new solutions or to reopen former streams. The master plan for the wastewater and water environment in Bergen includes the separation of wastewater and surface water on an area-by-area basis. For example, a strategy programme for water between the city centre and a lake area was planned by the Agency for Planning and Environment and the Agency for Water and Sewerage Works. New surface water management plans were drawn up to provide clean water to enrich the new pedestrian route. A study conducted on sustainable urban drainage systems in Norway has demonstrated that their benefits extend beyond environmental and sustainable water management: they also help to preserve cultural heritage sites such as Bryggen in Bergen (CIENS, 2015).

There is a greater focus on smart water management in new developments in Norway. For example, in the "Cities of the future" initiative from 2009 to 2014, several initiatives within the scope of the smart water concept were the focus in new development areas such as Haukåsvassdraget – a new city district in Bergen. Some of the characteristics of the development included local use of surface water based on principles such as retention and infiltration, retaining and using the natural watercourses and no pipe-based surface water system in the area. Integration of surface water management in the municipal master plan and subsequently in zoning and building plans was proposed. Modelling the sewer zones has enabled the municipal Agency for Water and Sewerage Works, Bergen to identify bottlenecks and possibilities of opening up channels and/or leading the surface water and wastewater through separate systems.

9.2 Oslo – challenges and opportunities

Oslo city is facing challenges mainly related to climate change, population growth, increasing urbanization and ageing infrastructure (Nie et al., 2011). A significant strain on the Oslo urban water system is anticipated in the future. Traditionally, urban water utilities made decisions based primarily on finance and engineering, but in the past few decades, significant focus has been placed on incorporating sustainability principles into the process (Mitchell, 2006). Integrated urban water resource management involves the planning and integration of supply, demand and source-substitution options for the sustainable, secure and reliable supply of water to meet projected future water demands of cities or towns. Moving along the path towards sustainability poses new challenges and demands for the utility.

Oslo has set one of the most ambitious carbon reduction targets among the 28 different cities surveyed by the EU with the aim of reducing emissions by 50% from the 1990 levels by 2030, and becoming carbon neutral by 2050. Oslo is at the top of the lowest CO_2 emissions category as a result of the use of renewable and alternative energy sources for public transport and its reduction of landfill emissions. In 2006, approximately 58,000 tons of CO_2 was avoided by capturing and using methane gas from landfill to generate energy for the city's district heating system. From 2009, rather than allow gas from its sewage plant to burn off and release its 12,000 tons of CO_2 a year, Oslo planned to harness it and convert it into biomethane to run a progressively increasing number of the city's public buses.

To address the future water management challenges, potential scenarios for the city of Oslo include: (1) addition of new water resources along its two water treatment works, (2) water demand management schemes by installing additional water meters for households, and/or (3) increase in the annual existing rate of pipeline rehabilitation, (4) water-saving options by introducing rainwater harvesting or (5) grey-water recycling systems to address the future water management challenges. Each scenario would require data such as water service historical records, system performance and projected changes in demand patterns. Factors considered for water demand predictions include potable, waste and recycled water average demand at source, the level of treatment required and the distribution level. With a range of alternative sources of supply comes the need to balance economic, environmental and social outcomes to ensure that the most appropriate schemes are implemented.

The resilience and robustness of the urban water system have never been important considering the challenges such as climate change and water scarcity as well as abundance, land-use change, population growth and also population shrinkage. These challenges can only be predicted with uncertainty and it is therefore possible that the "rigid" centralized systems that require long-term planning and significant capital investments might not address the future urban water management challenges efficiently.

The alternative is to make water infrastructure more flexible and adaptable (Urich et al., 2013). Decentralized systems are capable of adapting quickly when predictions are proven incorrect. However, redesigning well-organized centralized systems opens up a range of technical and socio-economic issues that require a comprehensive assessment to enable concrete results to be obtained that can be communicated to stakeholders and decision-makers.

Data on the impact of potential interventions on water supply savings, energy reductions and mitigation of greenhouse gas (GHG) emissions is of utmost significance to enable good decisions to be made. Social and operational costs and other externalities such as an increase in property values are becoming increasingly important when making a cost-benefit analysis of interventions in the urban water systems but at this stage lack a structured and systematic approach to make sound and reliable estimates.

Considering the range of opportunities and challenges, the city is an ideal test bed for investigation and implementation of various smart water scenarios such as leading the surface water and wastewater through separate systems and their integration with ICT tools as well as implementation of nature-based solutions with a special focus given to the potential of GHG reductions to meet Oslo's goal of becoming CO_2 neutral.

10. Community acceptance and adoption of localized/decentralized water systems

A shift to decentralized water management would also require public acceptance of those strategies particularly related to the use of reclaimed water. Community acceptance in adopting alternative reclaimed water sources has been reported to be influenced by risk perception, water culture and threat perception (Mankad and Tapsuwan, 2011). Health concerns appear to be the strongest barriers, limiting wider acceptance of alternative supplies for domestic uses.

In some cases, public awareness of the importance of local solutions such as green roofs appears to be limited and sometimes misunderstood. For example, a project involving building a green roof in the borough of Sagene in Oslo was cancelled due to the resistance from the building owner because of misunderstanding of the maintenance and impacts (Pedersen, 2014).

11. Conclusions

The need to rethink urban water solutions is emphasized globally and an integrated water management approach has been considered the most cost-effective route for addressing the urban water and climate challenges. The development of smart cities presents a number of technological, infrastructural and governance-related as well as social challenges: from the technological perspective, the biggest challenge is to re-engineer existing technologies and to develop new ones that are able to function together in systems. New solutions require more concrete and physical infrastructure as well as more integrated water management decision-support systems. For a city to become more efficient and responsive, data needs to be collected and shared among departments, agencies, partners and citizens: in many cases, data might exist but it often requires integration and interpertation to obtain meaningful insights.

Decentralized water management is based on the principle of integrated water cycle management and water-sensitive urban design. It considers sewage and storm water as resources rather than waste to be discharged, intelligent water and resource reuse, and relies on capturing the water rather than letting it flow through the pipes into the receiving waters.

Decentralized systems extend the flexibility of implementation on various scales, such as the allotment level (owned and usually operated by the home owner), cluster level (e.g. small-medium housing development with shared ownership), or a distributed level where the system could service a large housing development that is owned or operated by a water utility.

ICT has enabled collection of data and smart metering is growing in use in order to better monitor and manage water usage and leakages. Enabling technology to communicate and become multifunctional (linking with other smart city elements) generates data to enable understanding of how a city functions and use of that knowledge to improve the city to the benefit of its inhabitants and the environment.

The review evidenced that smart water solutions have been successfully implemented in Norway and that these solutions, owing to their flexibility, offer greater urban water management opportunities: decentralized local water management provides opportunities for better adaptation in the face of future uncertainties. Knowledge gaps regarding ongoing management requirements of decentralized systems, as well as their integration with existing centralized systems and potential implications (social, economic and environmental, etc.), need to be considered in a holistic way to identify potential opportunities and broader implementation of smart water systems. Energy is the largest controllable cost in water and wastewater operations, and the role of decentralized systems in reducing energy demands is less well understood. Furthermore, looking into how various interventions (new water resources, rainwater harvesting, wastewater reuse, etc.) impact on GHG emissions and water savings could assist in enabling greater understanding of the role of decentralized systems in achieving the sustainability goals. Oslo city's ambitious aims and variety of challenges make it an ideal test bed for testing new and innovative smart water solutions. Moreover, it provides numerous possibilities as the city has a great deal of untapped potential for smart water management.

With regard to the approach, this review demonstrates that the systematic evidence-based review principles are very useful for gathering evidence even with limited resources.

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