International experience on rainwater harvesting and stormwater utilisation – a literature review

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Sammendrag

Internasjonal erfaring om høsting og utnyttelse av regnvann og overvann. Norge har store ferskvannsressurser. Av den grunn har regnvannshøsting ikke vært et fremtredende tema. Regnvann (overvann) har i byer stort sett blitt behandlet som et problem man kunne løse ved å legge store nok rør og frakte det bort. Virkningene av klimaendringene har vært både økt antall flomhendelser og tørkeperioder. Disse endringene medfører at vi må ha systemer som både håndterer for mye og for lite vann med større svingninger enn vi tidligere har sett. Det har de siste tjue årene i større grad vært satset på lokal håndtering av overvann (LOD) og det finnes også eksempler på at man enkelte steder har inkludert regnvannshøsting i overvannssystemene (f.eks. i Oslo). Det har også blitt tatt i bruk mer naturbaserte løsninger innen overvannshåndtering. Men, det er ikke nok. I denne artikkelen er det gjort en gjennomgang av erfaringen at man har med regnvannshøsting og utnyttelse av overvann i utvalgte land både i Europa og andre deler i verden. Disse erfaringene kan tjene som eksempler for regnvannshøsting og bærekraftig overvannshåndteringen i norske byer.

Summary

Norway is a country with abundant water resources. Rainwater harvesting and stormwater utilization (RWH) has not been a central topic in Norway for a very long time. In recent years, however, we have experienced more frequent extreme storm events and less precipitation over other periods, because of climate change. We therefore need solutions to handle both too much and too little water problems. Rainwater harvesting has been recognised as one of the efficient measures for municipal stormwater management (for example in Oslo) and one of the sustainable nature-based solutions for flood control and drought mitigation and diverse social and environmental benefits. Despite of this awareness, the progress of rainwater harvesting in Norway is not yet much implemented in practices. This paper aims introduces international experience on rainwater harvesting and utili-

zation from several selected countries in Europe and other parts of the world, thus paves the ground for use of the rainwater resources smartly and sustainably, and build Norwegian cities to be more water resilient and water smart.

Introduction

Rainwater collected in lakes and reservoirs has been the main source for water supply in many countries, including Norway. However, rainwater in cities, also called stormwater, was treated as "a problem" in past engineering practices mainly because of the flood consequences and was thus drained away from urban areas by the designed urban drainage systems. Climate change has caused more frequent extreme rainfall events, both short-term heavier rainfall events and too little rain over a period of time. Increasing rain intensity caused more frequent flooding and flood damages and pollution of combined sewer overflow discharges (CSOs), and other impacts to the environment and daily life. There is also an increase in drought and water shortage in some periods and regions in Norway (e.g. 2018, 2021-2022)[1] and other countries in the world (e.g. WWAP, 2015; Han *et al.*, 2020; Nas *et al.*, 2020; Plester, 2022; Raimondi et al., 2023), which underlines the importance and the role of rainwater harvesting and utilization and recycling of wastewater resources. The increasing drought and floods and concerns about climate change and urbanization have highlighted the need to manage our water resources more sustainably. Beyond the use of rainwater and stormwater as important resources, it has been recognized as a valuable resource for diverse social and environmental benefits and being an indispensable part to build-up livable, healthy and resilient cities (Hatt *et al.*, 2006; the Senate, 2015; Teston *et al.*, 2022), rather than a nuisance to be disposed of quickly, especially in large urban centers.

[1] NTB (May 2, 2022). Oslo's drinking water is approaching a critically low water level: https://www.vartoslo.no/direktoratet-for-samfunnssikkerhet-og-beredskap-herv-colleuille-johan-marius-ly/oslos-drikkevann-naermer-seg-kritisk-lav-vannstand-niende-torreste-april-pa-ostlandet-pa-122-ar/372518.

Rainwater harvesting is to collect rainwater for a variety of potable and non-potable purposes, such as watering livestock, irrigation, cleaning, toilet flushing, etc. In general, a rainwater harvesting, and utilisation system consists of a catchment area (e.g. a roof), a pipe system that conveys the water to a storage tank and some kind of extraction system for usage (tap or pump). These systems can include a filtration or treatment system and a delivery system, depending on the requirements for water quality (Teston et al., 2022). The storage tank must also include an overflow pipe so that excess water can be drained away when it is filled up to capacity. Larger systems collecting stormwater usually have an important retention effect, reducing the run-off peak. These systems may also have an advantage to recharge the groundwater by letting the collected water seep into the ground.

Internationally, the practices on rainwater harvesting development can be dated back to ancient times (Campisano et al., 2017). However, the progress of rainwater harvesting, and utilization varies largely between regions. The past practices show that it was much faster and more comprehensive in the regions and countries where there is no sufficient freshwater resource available (e.g. Australia, Brazil, Egypt, Isael, North-western China, South Italy, etc); while it progressed slowly or just newly launched in other countries.

In Norway, rainwater harvesting, and utilization has been recently drawn attention of municipalities and publicans because of the forementioned occurrence of water shortages in Oslo and Easter regions. Municipalities like Oslo and Frogn encourage citizens to use rainwater to watering gardens in hot summer periods to save valuable drinking water resources (Nie, 2022). OsloVAV (2016) has already published a guideline of rainwater harvesting for garden watering, and in the years forward Oslo municipality aims to inspire rainwater harvesting as one of the measures for stormwater management, particularly for runoff detention for flood control and following utilization for sport or entertainment purposes, according to Lundin et al. (2021) and personal communication with Holbein and Braskerud in Oslo Municipality (2022). Klima 2050, a Centre for Research-based Innovation (SFI), developed research on storage and reuse of stormwater under climate change scenarios (Kjellsen, 2021; Sivertsen, 2021). Moreover, Norwegian institutes have actively developed and participated in European research in this topic areas, such as H2020 project SiEUGreen (2018-2022)[2] and Waste2Fresh (2020-2023)[3].

To summarize, rainwater harvesting is popular in the regions and countries where freshwater resources are insufficient to meet domestic or industrial consumptions. Differences in utilisation occurs due to differences in policy decisions, technical guidelines, financial support, and knowledge dissemination, including collaboration with stakeholders and engagement of citizens.

Objective and organization of the review article

Authors from several sectors of research, education, industry and NGO in Norway have contributed to this review paper in collaboration with experts in other countries. It is our hypothesis that rainwater harvesting and stormwater utilization in Norway need to be increased in the future, in particular due to changes in the climate and in society. The objective of this paper is to assess experiences related to rainwater harvesting and stormwater utilization from selected countries that have most experience within the topic areas.

The information presented in this paper is collected from a) an international webinar and b) literature review of selected open access publications.

An international webinar on Rainwater Harvesting and Stormwater Management was organised on 11 November 2021. Experts from several countries in the world were invited to share their knowledge and significant research and innovation outcomes in the topic areas, including remarkably ancient technology examples to the latest development. The literature review also assessed a number of international publications to support and complement the findings and statements presented in the webinar. In addition, other open access publications have been reviewed to extend the experience in other countries.

This article is divided into 4 sections: section 1 is a general information and definition of terms. Section 2 is a review of rainwater harvesting and stormwater harvesting and management experience in some selected countries; and then section 3 is findings and conclusions and finally section 4 formulated some recommendations to the water professionals in Norway.

Literature studies from several selected countries

Comprehensive stormwater harvesting in Australia and experience of rainwater harvesting in China, Portugal and Germany were reviewed and presented in this section.

Stormwater harvesting in Australia

Terms and definition

Stormwater is excess rainfall (after initial losses as depression, evapotranspiration and infiltration) converted to runoff from surfaces such as buildings, paved areas, roads, and open space. Stormwater harvesting (SWH) involves the capture, treatment, storage and use of the stormwater (The Senate, 2015), which is differentiated from RWH from the building roofs. Roof water is the component of stormwater that is generated from building roofs before it reaches the ground and mixes with other sources of stormwater. According to the classification of National Poly Industry, RWH refers only to the rain that falls on the roof, which can be harvested into a storage tank prior to contact with the ground[4]. In this regard, rainwater is distinguished as a particular part of the stormwater, and

2 Sino-European innovative green and smart cities: https://cordis.europa.eu/project/id/774233

3 Waste2Fresh: https://waste2fresh.eu/

4 National Poly Industry: https://nationalpolyindustries.com.au/2018/06/14/what-is-the-difference-between-stormwater-and-rainwater/

rainwater quality is usually much better than stormwater quality that is collected from other surface types, since water flowing over the ground generally contains many more contaminants including soil, organic matter, fertilisers from gardens, oil residues from driveways and others. Thus, rainwater can be easily utilized, while some pre-treatment of stormwater may be necessary for utilisation, depending on its application requirements (Hatt et al, 2006)

In terms of the definition of terms and practices in Australia, stormwater harvesting (SWH) is differentiated from rainfall or roof-water harvesting as mentioned in the prior section. It involves capture, treatment, storage and use of urban stormwater runoff. Rainwater harvesting has the added value that can ultimately reduce the volume of stormwater that enters drains or creeks, being one of the multi-benefits' solutions of stormwater management. Consequently, RWH projects such as rainwater tanks were raised in evidence (The Senate, 2015). It should be mentioned that the term of recycling of stormwater had been applied in Australia (e.g. Hatt and Fletcher, 2006). However, the term was switched from "stormwater recycling" to "stormwater harvesting" because the latter one can more accurately describe the practices, i.e. "harvesting" the stormwater (or rainwater), not recycling it in the way that wastewater is recycled (Fletcher, 2023).

Stormwater harvesting for non-potable and potable uses

In Australia, most properties are connected to a stormwater system. The stormwater system is separated from the sewer system. Unlike sewage, stormwater is generally not treated before being discharged back into waterways and the sea. Stormwater can also be collected as a valuable water source for non-potable purposes after being lightly treated, typically for irrigation of public parks, gardens, sports fields and golf courses, firefighting, environment flows, toilet flushing and other outdoor uses. According to Hatt *et al.* (2006), majority of the harvested stormwater is used for non-potable uses, of which over 44% is used for irrigation, 15% for toilet flushing and 13% for firefighting and rest for other indoor and outdoor uses (Figure 1 (a)). Common stormwater treatment solutions include litter and sediment traps, infiltration systems, swales and buffers, wetlands, ponds and other advanced treatment technologies (Figure 1 (b)).

There is also potential for potable use of stormwater. One successful example is the Orange city council project Blackmans Swamp Creek stormwater harvesting system for potable use (CRC, 2018), which is the first large scale, indirect-to-potable stormwater harvesting project in New South Wales (NSW) Australia. In this project the stormwater is captured and stored temporarily in the storage reservoir, which is connected to a pipe to the water supply source tank of the Orange city. This project is capable of providing around 1300 million litres

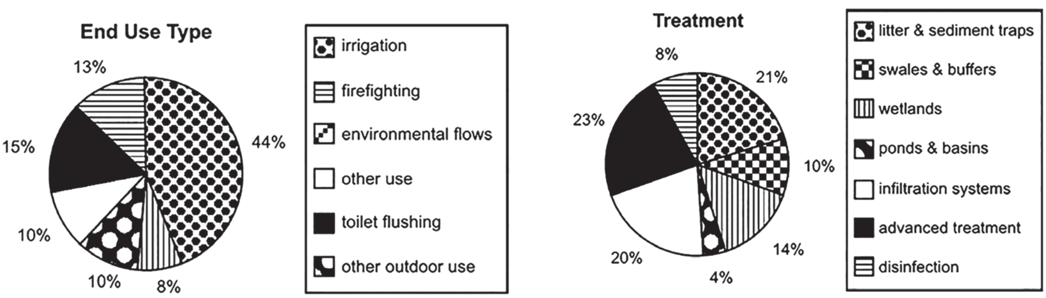

Figure 1. (a) Ration of Stormwater recycling end use type and (b) Ration of treatment solutions (Source: Hatt & Flethcher, 2006)

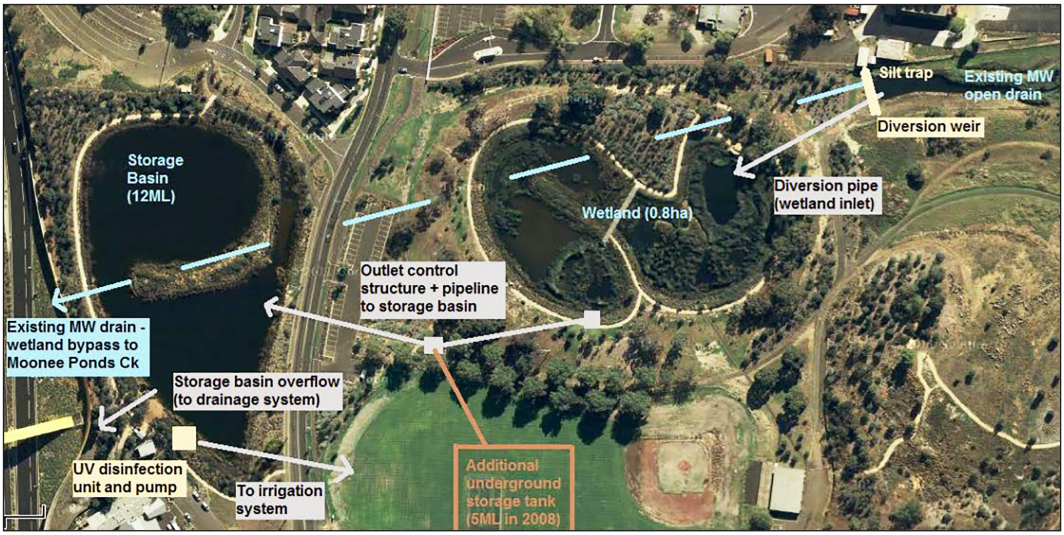

Figure 2. Schematic overview of Royal Park stormwater wetland and reuse system (Source: City of Melbourne, 2013)

of additional water into the Orange city's raw water supply each year from the city's stormwater system, meeting around 25% of the city's total water needs. In September 2019, because of low rainfall, there was no normal runoff, causing subsequent drought, fires and water shortage. Luckily, the stormwater harvesting system caught rainwater from streets and car parking lots from the two main rain events, provided water supply for eight days during the extreme periods[5]. Since the construction of the Blackmans Swamp Creek and Ploughmans Creek stormwater harvesting schemes, Council has also been investigating the best use of its stormwater. Dual pipe systems are becoming more common in new residential developments across Australia to reduce the consumption of drinking water and make the most of all water sources. Typically, one of the pipes in this dual pipe system is supplied with recycled wastewater and used to supply non-potable household uses (such as garden irrigation and toilet flushing), which do not require drinking water standard.

Another successful engineering practice is the Melbourne Royal Park Stormwater Harvesting project. As shown in Figure 2, stormwater is diverted from an open Melbourne stormwater drain, which collects water from a 187 ha catchment area. The diversion structure, which also acts as a sediment trap, allows only low flows into the constructed wetland which is about 0.8 ha. The treated water then flows into a 12 million litres storage basin, which allows overflow into Moonee Ponds Creek. This storage space was supplemented in 2008 by a 5 million litres' underground tank, situated below one of the sporting fields. To ensure the water is fit-for-purpose, it is treated with UV light and held in a distribution tank prior to use for irrigation of the neighbouring golf course, sports oval and parkland. To minimise human health risks, the water is supplied at night-time through spray irrigation. The system has a back-up supply with a connection to potable mains water. Two water hydrants are also located in an adjacent street to allow trucks to fill up and use the treated water for irrigation of streetscape features. This project demonstrates a comprehensive stormwater treatment (wetlands, ponds) and reuse system from source to end users, including also potable use (City of Melbourne, 2013).

The project also forms part of the Melbourne city's vision of "City as a Catchment" to create resilient water management solutions which buffer against the effects of drought and popula-

5 CRC for Water Sensitive Cities (2018): https://www.orange.nsw.gov.au/water/stormwater/

tion growth, whilst simultaneously reducing the impact of stormwater on receiving waterbodies and water courses and improving the ecological health of the site.

Stormwater quality, environmental and health risk

Depending on the use of stormwater for either non-potable or potable purposes, the various operational, environmental and health risks need to be handled. Public health and environmental risks arise as stormwater contains coarse materials and organic matter (such as sediment and leaves), chemicals and disease-causing microorganisms (pathogens) that need to be managed or treated. Operational risks for stormwater harvesting projects also arise because of stormwater quality. Among other problems, coarse and organic material carried by runoff can block pipes; high nitrogen and phosphate levels may support algal growth; and high iron concentration or high levels of calcium carbonate may block irrigation systems over time.

The concept of Water Sensitive Urban Design (WSUD) versus stormwater harvesting

The concept of Water Sensitive Urban Design (WSUD) was introduced in Australia in the

Figure 3. Laozi, an ancient Chinese philosopher

1990s (Fletcher et al., 2014). In the years that followed, the concepts of WSUD were elaborated and concretised through a series of position papers, including Lloyd et al. (2002) that describe WSUD as a "*philosophical approach to urban planning and design that aims to minimize the hydrological impacts of urban development on the surrounding environment. Stormwater management is a subset of WSUD directed at providing flood control, flow management, water quality improvements and opportunities to harvest stormwater to supplement water mains for non-potable uses*". During 2006- 2016, over 2000 WSUD systems were built, over 10 000 rain gardens were installed, over 25% householders in Melbourne have rain tanks and over 100 stormwater harvesting systems operated (Zhang, 2021). Integrated into a broader Water Sensitive Urban Design (WSUD) strategy, stormwater harvesting (SWH) provides far greater benefits than simply being a source of water supply in Australia. It reduces runoff rates and volumes, thus reducing flood risk and the associated discharges of pollutants from a catchment (Hatt et al., 2006; Flether, et al., 2014).

Rainwater harvesting in China

Rainwater harvesting in ancient China

China has a very long history of rainwater utilization, stretching from ancient times until today. Laozi, an ancient Chinese philosopher (Figure 3), said the supreme goodness is like water, which is good for all things, but does not fight with them, because water goes towards and stays in lower places where others do not. It is therefore the concept (Tao), near the Eternal.

Over thousands of years ago, Chinese developed several outstanding rainwater projects

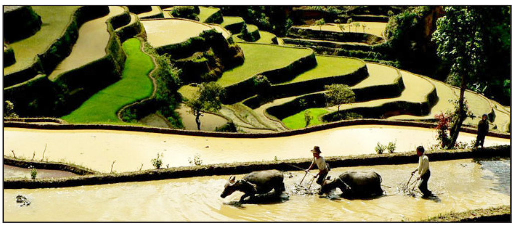

Figure 4. Hani Rice Terrace (https://www.fao.org/)

to cope with the violent climate and the natural disasters, typically floods and drought (Zhu et al., 2019). Some of these projects are still in use today, e.g. Hani Terrace in Yunnan was constructed by the Hani people, which are minorities who have lived in this area for more than 1300 years[6]. According to GIAHS, the main purpose of the terrace system is food production, but it also provides a lot of other services as soil and water conservation, protection against erosion and flood and more. The Hani villages are built on the mountainsides, with the forests above and the terraces below. The rainwater is led from the forest to the terraces and the surplus ends up in the river at the bottom of the valley, illustrated in Figure 4. The UN Food an Agricultural Organization has listed the Hani Rice Terrace as one of the globally important agricultural heritage systems[7]. Another successful example is Fushou drainage system of Ganzhou in Jiangxi province (Che et al., 2013). These projects evolved from the experience and knowledge accumulated through the co-existence of people with nature. The ancient Chinese knowledge behind these smart ancient practices is similar to the sustainable solutions applied for modern stormwater management today.

Modern rainwater harvesting development in China

Modern rainwater harvesting has also a long history in China. Taking Gansu province in North-western China as an example, it has less precipitation throughout a year than other regions in China, and therefore is categorised as one of the driest regions. Rainwater has been used as an important resource for potable and non-potable purposes in this region. Driven by the water shortage, rainwater harvesting has been an obligated measure to gain water for all necessary purposes. Accordingly, the local government of Gansu made a strategic decision to implement a "1-2-1" Rainwater Catchment Project. The project name of "1-2-1" refers to the structure of the support, it means that the government would support each family in the area to build one rainwater catchment with an area of 80–150 m^2 (This is the first "**1**"), two underground rainwater tanks each with storage capacity of 15–20 m^3 ("**2**"), one for domestic supply and another for irrigation, and one piece of land by the side of the house to be irrigated by the stored rainwater (the second "**1**"). In 1996, the government proposed another project for Rainwater Harvesting Irrigation. While "1-2-1" project supplied domestic water to meet their basic needs for daily consumption, the irrigation project opened up the way for the farmers to develop their household economy and livelihoods (Zhu et al., 2015).

Another example is Beijing, the capital city of China. It has also experienced severe water shortage for many years. Therefore, Beijing is one of the pioneer cities that launched urban rainwater harvesting (URWH) research and practices in the 1990s. Beside the research activities, Beijing Municipal Planning Commission (BJMPC) published a Notice to strengthen the planning and management of rainwater utilization projects (trial version) in 2012 (BJMPC, 2012). The Notice stated requirements for residential and non-residential RWH projects: (a) Residential projects with hard roof area of more than 10,000 square meters (inclusive) should be equipped with rainwater storage facilities of no less than 500 m^3. (b) For projects of non-residential buildings with a hard surface, including hard roof area and other hard surfaces of the non-residential building area of more than 10,000 m^2 (inclusive), rainwater storage facilities of no less than 500 m^3 should be built. Unfortunately, there is no statistical information as a proof to the implementation of the Political Notice in Beijing. Since 2012, some similar governmental policies and regulations on URWH have been development in several other cities, such as Nanjing in Jiangsu Province in 2013, Taiyuan in Shanxi province in 2014, Qingdao in Shandong province in 2014, Tianjin, Shijiazhuang in Hebei province and Suzhou in Jiangsu province in 2016, etc.

6 GIAHS, https://www.fao.org

7 Cultural Landscape of Honghe Hani Rice Terraces: https://whc.unesco.org/en/list/1111/

Sponge city development and rainwater harvesting

The Chinese Sponge city development programme introduced a comprehensive concept of runoff control and stormwater management, as well as related technical guidelines. The programme was launched in 2013, which provided a mode for cities and provinces of demonstration and implementation of the Sponge city approach (MHURC, 2014: Nie and Jia, 2018). The Sponge city concept includes four subsystems for runoff control, including runoff source control system, urban minor drainage sewer system, major drainage system, and catchment flood control system. The four sub-systems are connected to each other to address a chain of urban stormwater problems, such as total runoff volume control, runoff peak control, runoff pollution control, and rainwater harvesting. It contributes to tackle the comprehensive urban water-related challenges, including ecology, security, environment, resource management, culture, and other aspects. URWH is one of the measures for stormwater management, in addition to it is used as resources for multiple purposes. At the end of 2019, 606 km^2 of urban area has implemented sponge city-related construction in 30 national pilot cities and 90 provincial pilot cities, in total about 370 cities have prepared special planning of sponge city development, and about 10,200 km^2 of urban area will be developed or redeveloped according to sponge city requirements (Che & Zhang, 2019).

Technical codes and standards

Standardization is essential to ensure rainwater harvesting implementation practices. Technical code for rainwater collection, storage and utilization was first released as an industry standard in 2001, the code is sorted SL267-2001. It was the first industry standard for rainwater harvesting in China. This standard focuses on rainwater utilization in villages and towns, which also provides an important reference for RWH in urban areas. A national technical code for rainwater management and utilization for building and sub-district was released in 2006, which was revised in 2016 according to requirements of the Sponge city development, thus provides an important guidance and role for promoting rainwater harvesting in urban areas in the Sponge city development processes.

Beside the national standard, several cities and provinces released their local standards to guide the rainwater harvesting implementation practices. Among these local standards, one was released in Beijing in 2013, aiming to guide the design of stormwater management and harvest engineering performance (DB11/685-2013). This local standard was revised in 2021 according to requirements of the Sponge city development. According to the latest statistics, more than 40 local standards have been released in national pilots and demonstration cities of the Sponge city projects.

Rainwater harvesting in Portugal

Portugal, despite its relatively small size, presents a wide range of hydrologic conditions throughout its mainland territory. In fact, the average annual rainfall between 1960 and 1990 ranged from over 3000 mm in the North and Northwest to less than 600 mm in the South and Southeast. In addition to the spatial variability, the typical Mediterranean climate renders it also a temporal variability. With alternative wet and dry seasons along with cycles of dry and wet years are characteristics of the climate over Portugal mainland (IPMA, 2022). At the same time, urban water consumption in Portugal is responsible for nearly 50% of the cost with potable water supply, despite representing only 8% of the total water consumption.

Consequently, rainwater harvesting in Portugal, and other regions with similar contexts may yield a variety of objectives, including non-potable water uses and flood mitigation. The performance of RWH systems in Portugal have been assessed for residential (Silva et al., 2015), commercial (Sousa et al., 2018, 2019); and educational buildings (Almeida et al., 2021). Lúcio et al. (2020) assessed the performance of RWH systems also at various urban scales, from the individual household to the city, passing through the single building, the neighbourhood and district, and considering other potential water uses (e.g., public spaces irrigation and cleaning). These studies demonstrated the technical and financial viability of the RWH systems in all cases, even without accounting for the benefits for the society (e.g., environmental benefits from energy savings in potable water supply). Ongoing work is aiming at exploring the interaction between green roofs and RWH and assessing the impact of climate changes.

Rainwater utilization in Germany

In Germany rainwater harvesting and utilisation was introduced by some environmentally concerned people in the 1970s. The main idea was to save drinking water, and instead collect and use the rainwater for non-potable purposes as e.g., flushing toilets (Herrmann & Schmida, 1999). In 90es the state of the art has altered the pioneer's idea. The market for rainwater usage related products is booming and showing increasing economic importance. Rainwater harvesting has been applied increasingly to commercial applications in schools, car washing centres and industrial water demanding (Debus, 1999). According to Schuetze (2013) approximately 75,000 RWH systems are installed in Germany every year. The interest for RWH systems amongst homeowners had reached 1.8 million households utilizing rainwater in 2022 according to Plester (2022).

The development of RWH in Germany is, in addition to environmental concern, partly driven by policies and regulations and innovative technologies in addition to economy (Schuetze, 2013). Large scale RWH and utilisation systems are also installed in public and commercial buildings (Herrmann & Schmida, 1999). These systems are in addition to utilizing the water seen as important retention facilities in the stormwater system and are promoted and supported by the water and wastewater companies (Schuetze, 2013).

Currently, there is the tendency in the municipalities to split up the charges for urban drainage in a consumption (drainage)-dependent amount for wastewater and an impervious surface-area-dependent amount for stormwater. Thus, there is a permanent financial incentive to disconnect the roof runoff from the sewers. The two main issues in relation to the benefit of rainwater systems are thus: (1) evaluating the positive effects on the urban drainage system, especially for the widespread combined sewer systems in Germany and (2) the cost-effectiveness of private rainwater use. A cost-effectiveness balance on a catchment scale have shown that decentralised private storage tanks for rainwater harvesting can compete economically with centralised retention tanks, despite the requirements of the large specific storage tank capacity is necessary to catch the rainwater volume (Herrmann and Hasse, 1997, Deltau, 1998 and Stratmann, 1999).

Local authorities have also introduced financial incentives by splitting the wastewater fee in two parts: One part covering the wastewater treatment and another for stormwater management (Herrmann & Schmida, 1999; Schuetze, 2013). Households can save money on installing RWH systems, both on reduced use of drinking water and by retaining the stormwater. Some municipalities provide also subsidising, either directly or by cheaper loans, the installation of systems that can retain and utilise rainwater (Schuetze, 2013). By introducing these financial instruments, property owners are motivated to invest in measurers that will reduce the volume of stormwater entering the pipe system and the discharges of untreated sewage from combined sewer overflow in heavy rain situations. Investments in such decentralised stormwater management systems can reduce and/or postpone the need for investment in the centralised infrastructure. However, there are some concerns amongst utility owners as these investments in decentralised stormwater management systems will reduce their income and by that their ability to cover fixed cost and financing necessary upgrades of the systems (Schuetze, 2013). A widespread use of decentralised systems might therefor eventually lead to increasing expenses of central systems, because of e.g. lack of upgrade or maintenance. The environmental effects of such installations as reduced floods, reduced pollution and reduced freshwater extraction will still be a motivating factor for many property owners. In addition to this, authorities can encourage this development by subsidising the investment to ease the financial burden for property owners.

Findings and discussion

It is our hypothesis that rainwater harvesting and stormwater utilization in Norway need to be increased in the future and that it is necessary to look abroad for inspiration. Our findings are that many countries are harvesting rainwater and that many of the experience and solutions may be relevant for Norway.

Harvested rainwater is besides being a main resource for water supply, has been used globally for several types of non-potable purposes, such as flushing toilets, irrigating gardens, firefighting, car washing, top up swimming pools, urban agriculture, and industrial demands. Some rural buildings, cabins that do not have access to a reticulated water supply, and wastewater treatment infrastructure, depend upon groundwater and surface water sources in rivers, lakes and waterways, as well as harvested rainwater. Compared to the expenses of development of a long-distance water distribution and drainage system, cost of utilizing harvested rainwater is significantly lower than the centralized supply system. Therefore, there has been an increasing tendency of rainwater harvesting internationally.

The utilisation of harvested rainwater and stormwater varies in different countries and regions, depending on the available water resources and water demand, and are driven by economic development and political regulations. Learning experience of rainwater harvesting and utilization of stormwater from several selected countries, this paper highlights the following findings and conclusions:

Australia

Stormwater after being properly treated has become a safe water resource in Australia, particularly for non-potable uses, as such to save the clean water resource for potable uses only. Property owners can capture stormwater within their boundaries and use it for low-risk purposes such as garden irrigation and toilet flushing. Treating the stormwater can increase its useability, for example filling swimming pools, or even become a potable water supply although often not recommended. However, it can also increase the expenses, depending upon the requirements of uses and treatment processes. According to The Senate (2015), Australian cities must handle enormous volumes of stormwater. Not only does stormwater cause significant environmental damage, but it is also a resource that is clearly not utilised to its full potential. It also concluded that increased utilisation of stormwater will deliver various environmental benefits, beyond that generating other economic and social benefits.

Views on stormwater harvesting in Australia, the following aspects should be considered for improvements:

- Modelling suggested that more water could be harvested, however, there were significant challenges to overcome, typically space constraints for additional storage and a restricted diversion licence.
- Monitoring, although expensive, can allow early detection of potential problems. The monitoring campaign undertaken at Royal Park revealed that some parameters (such as iron, salinity and turbidity) measured up slightly above guideline values. These parameters will be monitored regularly in the long term to prevent any issues arising.
- Collaboration of researchers with stakeholders helped change the views of those initially sceptical with some later becoming ambassadors for the project implementation.
- A recent risk assessment report provides guidance on how and when communication between the agencies needs to occur, especially during abnormal operational conditions.
- Whether stormwater is used for non-potable or potable purposes, the various operational,

environmental and health risks it presents need to be handled. Public health and environmental risks arise as stormwater contains coarse materials and organic matter (such as sediment and leaves), chemicals and disease-causing microorganisms (pathogens) that need to be managed or treated. Operational risks for stormwater harvesting projects also arise because of stormwater quality.

China

China has a very long history in utilising rainwater, extending from ancient times until today. The ancient Chinese practices of handling and utilization of rainwater resources not only present wisdom from ancient times, but also provide a valuable cultural heritage for modern civilization and sustainable technological development. Further, the Chinese Sponge City is another significant development program for stormwater management under global changes and challenges of the current and future pressures on water resources. Rainwater harvesting is a sub-set of the comprehensive stormwater management. In this regard, rainwater harvesting is developed more comprehensively than merely being harvested for utilization. It contributes to tackle the comprehensive urban water-related challenges, including ecology, security, environment, resource management, culture, and other aspects.

Supervision and assessment have been followed-up to ensure efficient implementation and performance of the engineering solutions in the different pilots and cases in China (Wang et al., 2020).

Portugal

Rainwater harvesting in Portugal, and other regions with similar contexts may yield a variety of objectives, including non-potable water uses and flood mitigation.

Germany

The literature review of progress development of rainwater utilization in Germany introduced important policies and regulations that support the decentralized management, harvesting and utilization of rainwater, where such measures have been increasingly applied during the last few decades. The development and implementation of specific policies and regulations contributed significantly to that trend. They also work as incentives for the development of advanced technologies and businesses as well as the widespread and growing implementation of measures for decentralized rainwater management, harvesting and utilization by public and private actors. The addressed and supported measures can be assigned to the two focus areas: one is the "***Decentralized rainwater harvesting and utilization***", aiming for saving of precious freshwater resources and centrally supplied drinking water, another is "***Decentralized rainwater retention and management***", aiming for flood control and protection of existing infrastructures and ecosystems. The decentralized management of rainwater and its separation from combined sewer systems at the source is generally regarded as the state of the art and basic condition for sustainable municipal wastewater management.

A widespread use of decentralised systems might eventually lead to a potential challenge of increasing expenses of the centralized urban drainage infrastructure system, because of e.g. lack of finance for upgrade or maintenance. The climate and environmental effects of such installations and upgrades as reduced floods, reduced pollution and reduced freshwater extraction will still be a major motivating factor for water authorities, water utilities and property owners.

Conclusion and recommendations

Learning from the international experience, especially Australia and China, rainwater harvesting and stormwater utilization are treated as one of the efficient measures for stormwater management. It provides far greater benefits than simply being a source of water supply, particularly:

- Increased utilisation of stormwater can contribute to stormwater retention, flood and pollution control, deliver various environmental benefits, beyond that generating other economic and social benefits.
- Integrated into a broader Water Sensitive Urban Design (WSUD) strategy, stormwater harvesting (SWH) provides far greater benefits than simply being a source of water supply in Australia. It reduces runoff rates and volumes, thus reducing flood risk and the associated discharges of pollutants from a catchment.
- In the Chinese Sponge city programme, RWH is introduced a subsystem of urban runoff management, including runoff source control system, urban minor drainage sewer system, major drainage system, and catchment flood control system. The four subsystems are connected to each other to address a chain of urban stormwater problems, such as total runoff volume control, runoff peak control, runoff pollution control, and rainwater harvesting and utilization. It contributes to tackle the comprehensive urban water-related challenges.
- The experience of rainwater harvesting and utilization in Germany also highlight that the climate and environmental effects of such installations and upgrades as reduced floods, reduced pollution and reduced freshwater extraction will still be a major motivating factor for water authorities, water utilities and property owners. The addressed and supported measures can be assigned to the two focus areas: one is the "Decentralized rainwater harvesting and utilization", aiming for saving of precious freshwater resources and centrally supplied drinking water, another is "Decentralized rainwater retention and management", aiming for flood control and protection of existing infrastructures and ecosystems. The decentralized management of rainwater and its separation from combined sewer systems at the source is generally regarded as the state of the art and basic condition for sustainable municipal wastewater management.

This assessment of rainwater harvesting practices in selected countries has shown that rainwater harvesting and stormwater utilization does not only contribute to being a source for water supply, but also contribute to reduced urban stormwater related challenges. Reduced runoff volumes, reduced peak runoff and reduced discharge of pollutants are co-benefits provided by rainwater harvesting. Hence, rainwater harvesting should be put on the national agenda along with other measures to address urban stormwater challenges.

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