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Mitigating flash flooding in the city: Drain or harvest?

Tebogo V. Siphambe[a], Abdurrahman Aliyu[a], Kawter Souadji[a], Samuel Ahana Bayongwa[a], Tiwangye Amans[a], Hermann Fomena-Tchinda[a], Pinisikin Yasmina Banaon[a], Ciniso Sizwe Gina[a], Hidayat Ame Vuai[a], Abdikadir Mohamud Farah[a], Adji Billo Niang[a], Abdelhak Taicha[a], Seifeldin Ahmed[a], Ahmed Bashir[a], Chérifa Abdelbaki[a], Tulinave Burton Mwamila[b], Willis Gwenzi[c,d,e], Esther Laurentine Nya[f] and Chicgoua Noubactep[g,h,i,*]

[a] Pan African University Institute of Water and Energy Sciences – PAUWES. c/o Tlemcen University, B.P. 119, Pôle Chetouane, Tlemcen 13000, Algeria
[b] Water Institute, Ministry of Water, P.O. Box 35059, Dar es salaam, Tanzania
[c] Biosystems and Environmental Engineering Research Group, 380 Adylin, Westgate, Harare, Zimbabwe
[d] Current address: Grassland Science and Renewable Plant Resources, Faculty of Organic Agricultural Science, University of Kassel, Steinstrasse 19, D-37213 Witzenhausen, Germany
[e] Current address: Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Max-Eyth-Alle 100, D-14469 Potsdam, Germany
[f] Faculty of Arts, Letters and Social Sciences, University of Maroua, P.O. Box 644, Maroua, Cameroon
[g] Department of Applied Geology, University of Göttingen, Goldschmidtstraße 3, D-37077 Göttingen, Germany
[h] Faculty of Science and Technology, Campus of Banekane, Université des Montagnes, Bangangté, P.O. Box 208, Cameroon
[i] Centre for Modern Indian Studies (CeMIS), University of Göttingen, Waldweg 26, D-37073 Göttingen, Germany
*Corresponding author. E-mail: cnoubac@gwdg.de

CN, 0000-0002-3277-5148

ABSTRACT

Rainwater harvesting (RWH) is principally based on collecting, storing, and using rainfall which would otherwise be lost as surface runoff. Runoff threatens in several ways: accelerating erosion, intensifying flooding, and reducing groundwater recharge. Therefore, purposely retaining rainfall in the urban water cycle rather than draining has several positive impacts on designing sustainable cities. This work presents a proposal on how to avoid flooding in cities by systematically harvesting, storing rainwater, and using it for multiple purposes. The concept of RWH presented here has the potential to be a radical innovation to solve the social, economic, and environmental challenges associated with flash flooding. Each residence is regarded as a water production unit. Depending on the climatic conditions, people can meet their water needs on a local household basis, or alternatively use piped water as a complement. By infiltrating rainwater, groundwater is locally recharged and downstream wells are more productive. The implementation of this idea involves entrepreneurial agency that challenges existing structures, rather than adapting to them. Clearly, social entrepreneurship and social innovation are expected to catalyse the realization of this social innovation, also in rural areas. It is about mobilizing ideas, capacities, and resources to create a sustainable social transformation.

Key words: decentralized water management, flash floods, flood risk management, irrigated agriculture, rainwater harvesting

HIGHLIGHTS

- Rainwater harvesting is a well-established tool to retain water within the city.
- Harvested rainwater is conventionally used for non-potable used (clean and green city).
- The potential of rainwater for safe drinking water provision has been largely overlooked.
- A new concept for urban water management, encompassing flash flood mitigation is presented.
- Harnessing active engagement of all citizens facilitates the efficiency of this concept.

1. INTRODUCTION

Flooding fundamentally results from heavy rainfall and snowmelt. Flash flooding occurs often yearly in many cities, negatively impacting human lives through anxiety and post-traumatic stress, depression, drowning, water-borne and rodent-borne diseases, homelessness, physical injuries, and vector-borne diseases (Nkwunonwo 2016; Egbinola *et al.* 2017; Echendu 2020; Legese & Gum 2020). Causes of flooding include climate change (e.g., more frequent and severe rainfall events), poor land use planning due to lack of awareness of flood risk, limited efforts towards flood disaster risk reduction, rapid population

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growth, and rapid urbanization (Gwenzi & Nyamadzawo 2014; Nkwunonwo 2016; Valdez *et al.* 2016; Egbinola *et al.* 2017; Prakongsri & Santiboon 2020). The factors influencing the severity of flooding include: (i) the amount of precipitation that falls in the watershed and tributaries, (ii) intensity of rainfall relative to infiltration rate, (iii) land cover and land use changes (e.g., grey infrastructure, vegetation, paved surfaces), (iv) nature and structure of the soil, (v) size and shape of the catchments, and (vi) topography of the catchments (Gwenzi & Nyamadzawo 2014; Han & Nguyen 2018; Fioramonte *et al.* 2022; Vitale & Meijerink 2023; Waseem *et al.* 2023).

The diversity of causes of flooding and factors influencing its severity suggests that predicting floods and their impacts is a complex task. In fact, mitigating flood impacts implies a flood alert system managed in collaboration with a meteorological forecasting agency. In many countries of Sub-Sahara Africa (SSA), such systems are not available or lack monitoring equipment and capacity, and thus, mitigation strategies are very poor (Egbinola *et al.* 2017; Legese & Gum 2020). This sad situation seems impossible to address without high financial investments. Fortunately, local knowledge on water capture and conservation exists, including bunds, check dams, infiltration pits/ponds, percolation tanks, storage tanks, and terracing (Hasse 1989; Vavrus 2003; Adams *et al.* 2010; Kim *et al.* 2016; Woodhouse *et al.* 2017; Silayo & Pikirayi 2023). This study postulates that coordinated strategies to reduce flooding are realizable combining local rainwater harvesting (RWH) knowledge and recent scientific evidence. In this effort, the involvement of all stakeholders and communities in the project cycle from conceptualization, design, implementation, operation and performance monitoring, and evaluation is fundamental. This knowledge can be complemented by scholarly engineering tools to maximize the volume of harvested, infiltrated, and stored water.

The present study is a qualitative conceptual attempt to provide an affordable and applicable answer to questions regarding flood mitigation in developing countries in the absence of (i) reliable data for flood modelling and (ii) capitals for financing corresponding infrastructures. The study is driven by two key issues: (i) to demonstrate the key role of RWH in flood risk reduction and (ii) to promote awareness of rainfall as a resource to be harnessed. The slogan is 'Flash flood = non-harvested rainwater' and is related to an old Sri Lankan vision of not allowing 'a single drop of water falling as rain flow into the sea without being used for the benefit of mankind' (Shannon & Manawadu 2007; Nya *et al.* 2023). Flooding or excess rainfall occurs when rainfall intensity exceeds the infiltration rate of the soil (Umar & Gray 2023). This implies that avoiding the runoff of this excess rainfall automatically avoids flooding and related environmental consequences.

The presentation starts with a description of the hydrologic cycle (Section 2), followed by an overview of the current perception of the potential of RWH to address flash flooding (Section 3). Section 4 conceptualizes the future of water management rooted in RWH, and Section 5 prepares its realization. Section 6 presents some aspects of how the new approach will increase the living standards in the city and formulates some recommendations for its realization. A short conclusion (Section 7) closes the presentation.

2. THE HYDROLOGIC CYCLE

2.1. General aspects

At a global scale, the Earth's atmosphere, oceans, and land surface act as a 'closed system' in which water continuously moves along a variety of phases (liquid, gaseous, and solid) (de Assis Matos de Abreu *et al.* 2005; Legates 2007; Prakongsri & Santiboon 2020). This cycle involves the continuous circulation of water from raindrops in the atmosphere to soils and subsurface aquifers and back (Figure 1). In this work, it is operationally considered that there is no snow, and all waters originate from rain as is generally the case in tropical environments such as those predominant in SSA (Ako Ako *et al.* 2022; Nya *et al.* 2023).

The hydrologic cycle begins with precipitation or rainfall. Once rainwater reaches the ground, for example, at the top of a hill (Figure 1), a fraction is infiltrated into the soil to form soil water, while part of it forms groundwater, a second fraction is evaporated back into the atmosphere (next rain), and the last fraction runs off. The first fraction is divided into two parts: (i) 'permanent' groundwater or aquifer and (ii) outflowing groundwater progressively forming springs, and baseflow in streams and rivers and ending into the ocean (Taghavi-Jeloudar *et al.* 2013; Bensi 2020). Permanent groundwater includes 'fossil' groundwater characterized by long residence times of more than 12,000 years (GebreEgziabher *et al.* 2022). Lakes can originate from both 'permanent' and outflowing groundwater, while evaporation occurs at the surface of all open water bodies, including lakes, ponds, and oceans. The last source of water vapour in the atmosphere is evaporation from soil and transpiration (evapotranspiration). When moist air is lifted, it cools, and water vapour condenses to form clouds and returns to the Earth's surface as precipitation (Figure 1). It is very important to recall that, in the short term, non-'fossil' groundwater

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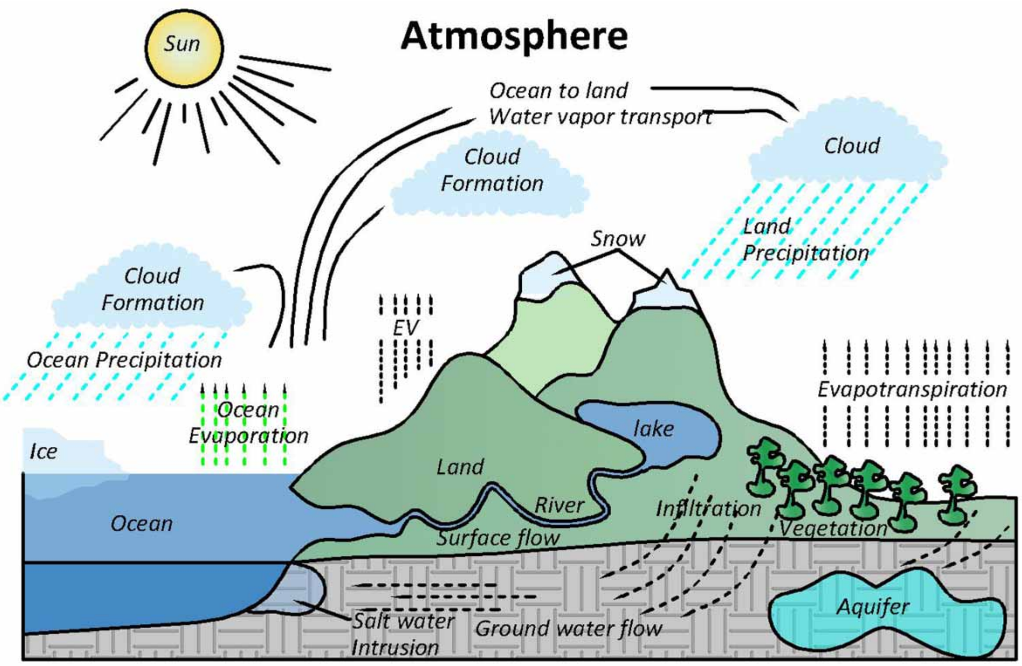

Figure 1 | An overview of the hydrologic cycle depicting all its components.

seeps its way into springs, streams, rivers, and oceans. In other words, springs, streams, and rivers are just 'delayed' runoff from rains temporarily stored in aquifers then later released as baseflow. In coastal areas and even on islands, there can be saltwater intrusion if the groundwater level is lowered too much by excessive pumping (Henriquez 1962; van Buurt 2018; Pembe-Ali *et al.* 2021). The present study is focused on direct runoff or excess rainfall which is regarded as the main cause of flash floods in urban areas. The 'direct' runoff empties into lakes, rivers, streams, and lastly back to the oceans, where evaporation occurs to form the next rain (Figure 1).

2.2. The mathematics of the water cycle

Section 2.1 recalls that the water cycle has no starting or ending point, rather it is a constant state of flux. In fact, neglecting the solid phase, water permanently changes its state from liquid to vapour and then back again. The long-term water balance without a change in storage can be summarized in Equation (1):

$$P = E + I + R \tag{1}$$

where P stands for precipitation, E for evaporation, I for infiltration, and R for runoff. Condensation is not considered in Equation (1) because it is part of evaporation and precipitation, showing clearly that all terms of Equation (1) are interrelated. In particular, infiltration corresponds to rainwater seeping into the soil, and this infiltrated water is either utilized by plants or replenishes the aquifer (groundwater recharge). Replenishing the aquifer corresponds to making important sources of fresh groundwater more productive, mainly springs, boreholes, and wells (Figure 1). On the other hand, runoff occurs ideally when the soil's surface is saturated or when rainfall intensity exceeds the infiltration rate, and the soil cannot absorb more water. When the soil is covered by grass and plants, the leaves and the roots enhance the infiltration process and uptake of soil moisture. In contrast, when rain falls onto hard surfaces (rocks, paved areas) or impervious soils (e.g., clayed soils) and surfaces (e.g., roofs, pavements), it generates runoff that causes erosion and ends up in surface water bodies (e.g., lakes, streams, rivers, oceans).

The natural water cycle has been regulating life on the earth for millions of years. Five major benefits of this cycle are aquifer recharge, climate regulation, erosion control, flood control, and freshwater supply (Serrao-Neumann *et al.* 2017; Shahid *et al.* 2018; Shahid *et al.* 2021). For example, when water evaporates, it absorbs heat energy from the sun to cool the

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environment. Precipitation helps replenish the soil moisture, which is essential for plant growth and crop production. The current global urbanization movement originating from Europe during the 1830s has significantly impacted the natural water cycle in urban areas (Brown *et al.* 2009; Wong & Brown 2009; Angrill *et al.* 2012; Nkiaka 2022). This is because the construction of characteristic grey infrastructures with impervious surfaces (e.g., airports, buildings, bus stations, roads) has profoundly modified I and R values in Equation (1). The prevalence of grey infrastructures in cities has led to various social-economic and ecological implications that have in turn led to a rethink in the way to promote resilient urban systems, starting with better approaches of water resources management with RWH as a main pillar (Brown *et al.* 2009; Wong & Brown 2009).

Designing RWH infrastructures (RWHIs) is based on local precipitation (e.g., in m/year), and catchment area (e.g., roof of a residence). The RWH potential is calculated using Equation (2) (Kim *et al.* 2016; Mwamila *et al.* 2016; Bui *et al.* 2021; Fioramonte *et al.* 2022; Ferreira *et al.* 2023):

$$Q = C \times P \times A \tag{2}$$

where Q represents total harvestable runoff from roof (m^3), C indicates the coefficient of runoff or collection efficiency (e.g., 0.9 for galvanized iron sheet) (Anchan & Prasad 2021), P is the intensity of rainfall (m/y), and A represents total rooftop catchment area. Besides the roof type, the runoff coefficient also accounts for evaporation loss, and possible first flush diversion (Demeke & Amali 2023).

The volume of rainwater (Q) collected everywhere can be used for all needs. Depending on the intended uses, corresponding treatment systems should be designed. In particular, only the required potable water volume (Q_{potable}) is treated to the drinking water standard. The RWH potential (Equation (2)) can be expressed through the following equations:

$$Q = Q_{\text{potable}} + Q_{\text{non-potable}} \tag{3}$$

$$Q_{\text{non-potable}} = Q_{\text{toilet}} + Q_{\text{irrigation}} + Q_{\text{washing}} + Q_{\text{infiltration}} \tag{4}$$

where Q_{toilet} represents the volume of water required for use in toilet flushing (including urinals), $Q_{\text{irrigation}}$ represents the volume of water required for irrigation, Q_{washing} considers the volume of water required for use in cleaning and washing, and $Q_{\text{infiltration}}$ represents the volume of water locally infiltrated.

Conventionally, Q is calculated based on the water demand. For example, the calculation of Q_{potable}, Q_{toilet}, and Q_{washing} considered the number of occupants of a residence, while the calculation of $Q_{\text{irrigation}}$ is made considering the area of a garden and the crop water requirements (Sanches Fernandes *et al.* 2015; Vialle *et al.* 2015; Ferreira *et al.* 2023). The irrigation water requirements depend mainly on the type of crop and weather conditions. This work, on the contrary, advocates for harvesting the maximum possible volume of water at the residential level. The number of occupants and their water consumption then determine the volume of overflow or excess water to be directed to community tanks.

There is currently confusion in the scientific literature concerning the way to design the RWH infrastructure. This confusion results from the evidence that Equations (1)–(3) have been mostly considered independently (Amos *et al.* 2013; Vialle *et al.* 2015; Serrao-Neumann *et al.* 2017; van Ginkel *et al.* 2018; Huang *et al.* 2021a; Ferreira *et al.* 2023). In fact, while Equation (1) advocates for systematic RWH to mitigate the reduced infiltration caused by artificial impervious areas, the literature uses Equations (2) and (3) to discuss whether rainwater should be harvested.

An increasing body of literature exists on the design of RWH for various settings (Hasse 1989, Fonseca *et al.* 2017; Nguyen & Han 2017; Han & Nguyen 2018; Han 2020; Semaan *et al.* 2020). Thus, a detailed discussion of the design procedure is beyond the scope of the present study. Briefly, the available design approaches for RWH can be broadly grouped into two:

(i) One for areas with long-term high-resolution rainfall data (daily) (e.g., developed countries). An example of such a design approach is described in earlier studies (e.g., Fonseca *et al.* 2017; Han & Nguyen 2018; Semaan *et al.* 2020).
(ii) The other one is for data-scarce settings, ideal for low-income countries. An example of how to design an RWH is settings with limited or scarce rainfall data is presented in the study by Nguyen & Han (2017). This approach is appropriate for low-income regions such as Africa with sparse or no hydrometric stations (Cheo 2018; Nya *et al.* 2023).

Studies have also evaluated the performance of RWHs for water supply reliability (Amos *et al.* 2018; Bak *et al.* 2020; Lee *et al.* 2021). For evaluating water supply reliability, two variables are often used: (i) rainwater utilization ratio (RUR) and (ii)

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number of no-water days (NWD) (Mun & Han 2012; Mwamila *et al.* 2015). RUR also referred to as rainwater use efficiency is the ratio of the amount of rainwater supplied to users to the total rainwater harvested from a given catchment area (Bak *et al.* 2020). NWD, which measures reliability, refers to the number of days in a year when stored water is less than the 1-day demand. NWD is related to the concept of security, which is the average number of days in a given period (e.g., a year) with zero water supply (Umapathi *et al.* 2019). Other studies have also developed and applied various parameters to evaluate the flood mitigation potential of RWH (Freni & Liuzzo 2019; Cristiano *et al.* 2023).

2.3. Driving forces for RWH

RWH has not yet been addressed on a holistic basis. Equation (1) suggests 'harvest whenever you can' or harvest rainwater because it is a natural resource like coal ('white coal') or gold ('blue gold'). Clearly, harvesting and even recycling rainwater should be regarded as resource conservation par excellence, while using the best available technology. Instead, reasons currently justifying RWH while using Equation (2) include: (i) economic feasibility ('harvest if it is affordable'), (ii) water conservation ('harvest it for non-potable uses only' – citizen's option), (iii) as an alternative in areas lacking centralized water supply (e.g., mountain communities, remote areas, rural communities), (iv) as an alternative in areas lacking non-polluted surface water (e.g., presence of As, F, salinity, or U), and (v) to avoid erosion (environmental protection) and flooding (emergency relief). These five reasons correspond to the motivation of individual stakeholders to harvest rainwater (Hasse 1989; Han 2013a, 2013b, 2020; Fu & Butler 2021). Whenever it rains, a more or less large volume of runoff is not harvested. The fundamental question is 'Why invest money for networks and hydraulic structures to collect and channel rainwater to the river/sea rather than to harvest and use it?'

This question is alien to a Western-educated person as recently recalled by Gwenzi *et al.* (2023). In fact, with the 'sanitary revolution' or 'hygiene movement' of the 19th century, rainwater was relegated to something less than waste. This is because rainwater was a disturbing factor in efforts to design reliable sewerage systems (Cook 2001; Hughes 2013; Han 2013a, 2013b; Geraldi & Ghisi 2017; Snir *et al.* 2022). This view completely contrasts the old wisdom that rainwater is the least polluted water source on the earth (Davis 1891; Han 2013a, 2013b; Han & Nguyen 2018; Akkerman 2020; Huang *et al.* 2021a; Nguyen *et al.* 2021).

2.4. Rainwater in the city

The conventional approach, known as urban drainage, to avoid the 'direct' runoff causing flash flood in cities has been to drain rainwater as quickly as possible to the next water course (river or stream) (Nichols 1885; Parry 1885; Hughes 2013; Snir *et al.* 2022; Gwenzi *et al.* 2023). This solution requires proper urban planning and should be dynamic as cities and poorly planned and unplanned urban settlements are growing almost randomly (urban sprawl) and more areas are made impervious (Lal 2015a, 2015b; Nkiaka 2022; Demeke & Amali 2023). While engineering tools and political will may exist to solve the arising problems, there is a lack of financial support in low-income communities in SSA and in the MENA countries (Wahab & Ojolowo 2013; Celik *et al.* 2017; Loudyi & Kantoush 2020; Echendu 2022; Goetz *et al.* 2023). Therefore, alternative, affordable, and applicable solutions are urgently needed. A good and immediately realizable idea is to incorporate indigenous and modern RWH techniques into urban flood management. Making flood management the main target (disaster prevention or emergency relief) will sustainably enable access to domestic water, promote urban agriculture, promote household food security, and combat poverty (Hasse 1989; Han 2023a, 2023b). This is because disaster prevention is clearly one of the regalian functions of the State (protection of citizens) and transcends various spatial planning scales (at communal, regional, and national levels), while access to clean water, food security, and poverty reduction can be mistakenly considered as charitable interventions, particularly in small cities and rural areas. The regalian task here entails that a sovereign State has the role to protect its population (domestic security) (Chopin & Jamet 2016).

3. RWH AGAINST FLASH FLOODING

Section 2 has suggested regarding rain as the main water source on the earth, which means rainwater is the 'mother' of both river and groundwater on which the conventional water supply relies. Regarding rain as the mother of all waters (Figure 1) implies a revision of conventional considerations, restricting RWH to a tool to diversify local water sources (Agarwal & Narain 1999; Farreny *et al.* 2011; Snir *et al.* 2022; Soh *et al.* 2023; Vitale & Meijerink 2023). The view presented herein corresponds to the Kilimanjaro concept, advocating for the creation of appropriate water infrastructures culminating in drainage networks for harvested rainwater (Marwa *et al.* 2018; Qi *et al.* 2019; Nya *et al.* 2023). The design of such networks can be

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adapted from conventional systems for collecting wastewaters (Moss 2000; Howe *et al.* 2012; Demeke & Amali 2023) and have the potential to mitigate water stress related to the population growth and climate change (Agarwal & Narain 1999; Cain 2014; Echendu 2020; Soh *et al.* 2023).

One key issue in discussing the suitability of rainwater for domestic uses has been its potability (Hasse 1989; Farreny *et al.* 2011; Snir *et al.* 2022; Nya *et al.* 2023). However, the following two key points are generally recognized: (i) carefully collected rainwater is of good drinking quality (Davis 1891; Kim *et al.* 2016; Han & Nguyen 2018; Bui *et al.* 2021; Akkerman 2020; Snir *et al.* 2022) and (ii) collecting rainwater onsite eliminates their possible contamination with pollutants carried by urban runoff (Faragò *et al.* 2019; Snir *et al.* 2022). This implies that even in cases where harvested rainwater is polluted, the pollutants are known and affordable treatment options exist (Alsulaili *et al.* 2020; Huang *et al.* 2021b; Kearns *et al.* 2023; Nya *et al.* 2023). Clearly, RWH should not only be regarded as a simple tool to support household level water demands or as a useful practice to mitigate the lack (Hasse 1989) or depletion (Snir *et al.* 2022) of conventional water resources. Rather, RWH (i) prevents rainwater from accumulating and reaching the streets in large quantities, (ii) reduces overloading urban drainage systems (e.g., reduced runoff volumes and peak flows), and (iii) potentially avoids flash flooding (Agarwal & Narain 1999; Wahab & Ojolowo 2013; Loudyi & Kantoush 2020; Echendu 2022).

A further advantage of RWH as derived from Figure 1 is artificial infiltration to recharge the aquifers, and thus, locally making springs and wells more productive (Adams *et al.* 2010; Mupangwa *et al.* 2012; Woodhouse *et al.* 2017; Chitata *et al.* 2021). This knowledge is indigenous in several societies and has been applied without interruption in Sri Lanka for the past 1,000 years, as an excellent example of combining rainfall and runoff harvesting system (Smakhtin & Piyankarage 2003; van Meter *et al.* 2014; Kirshanth & Sivakumar 2018; Ramabrahmam *et al.* 2023). King Parakramabahu, the inventor of this civilization in Sri Lanka once said: 'Let no drop of water flow to the sea unused by man.' The realization of this vision implied the intensive collection and storage of rainfall and surface runoff in human-made reservoirs (e.g., cisterns, ponds, and tanks) and provided water for domestic uses, fish farming, irrigation, and livestock rearing (Hasse 1989; Han & Nguyen 2018; Han 2023a). The reservoirs are in general located in a cascade-like manner along shallow valley courses. These reservoirs are connected by canals or furrows and are built as a complex system of floodwater harvesting, water storage, and water distribution (Jayatilaka *et al.* 2003; Smakhtin & Piyankarage 2003). This wisdom is found in some modern rainwater slogans like: 'all water, for all and by all' (Han 2023a), 'catch it when you can', 'catch it where it falls', 'from drain city to rain city' (Han 2013b), or 'never let rainwater flows to the sea'. This view can be translated into the following simple equation: Flash flood = Non-harvested rainwater. Coming back to Equation (1), harvesting rainwater corresponds to reducing the R value (runoff) while increasing the I value (infiltration). As concerning the E value, its modification depends on where harvested water is stored. If rainwater (RW) is stored in an open pond, the E value increases. If RW is stored in a buried cistern, the E value is significantly reduced. The extent to which all these values are modified depends on the volume of harvested rainwater (storage capacity), which is determined by Equation (2).

Summarized, flooding arises from excess rainfall, when rainfall intensity exceeds the infiltration rate of the soil. Excess water is intensified by the abundance of human-made impervious surfaces within the city. In the absence of modern infrastructures, a considerable fraction of falling rain is retained (i) in soil, lakes, and ponds or (ii) by vegetation. In natural or undisturbed ecosystems, the non-retained water typically flows as surface runoff without or with limited destructive potential (Wahab & Ojolowo 2013; Loudyi & Kantoush 2020). The recognition that the removal of these natural water retaining features is the roots cause of urban flooding has led to mitigation tools like low impact development, sustainable drainage systems, and sponge cities (Eckart *et al.* 2018; Lashford *et al.* 2019; Dijk *et al.* 2020). However, these approaches are rooted in intensively draining rainwater away from residential areas (homes) with a better control of issues like: (i) blocked hydraulic structures and (ii) siltation of water channels. In contrast, rainwater management as introduced herein (Kilimanjaro concept) creates a network to enable multiple uses of any drop of rainwater on a home-to-home, farm-to-farm, and hill-to-hill basis (Marwa *et al.* 2018; Qi *et al.* 2019) as it has been done in Sri Lanka for centuries (Jayatilaka *et al.* 2003; Pandey *et al.* 2003; Smakhtin & Piyankarage 2003; van Meter *et al.* 2014).

The Kilimanjaro concept roots integrated water resources management (IWRM) on RWH while considering the specific needs of all stakeholders (Ndé-Tchoupé *et al.* 2019; Pembe-Ali *et al.* 2021; Nandi & Gonela 2022; Nya *et al.* 2023). Herein, it is about avoiding flash floods for the whole urban population. The presentation until here has demonstrated the suitability of RWH to reduce the volume of runoff resulting from impervious urban surface. The focus of this study is to showcase the potential of RWH in significantly reducing surface runoff to the extent that the risks of urban flood are practically eliminated. This implies the construction of community cisterns, retention ponds, and tanks which can be emptied in a controlled manner

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depending on the weather forecast. Even in the absence of any reliable system for weather forecast, intensively harvesting rainwater certainly reduces the intensity of floods. Thus, the concept described herein is immediately applicable using available or adaptable methods for water conservation (Hasse 1989; Dallman *et al.* 2016; Dallman *et al.* 2021; Han 2023a).

It is very important to insist on the fact that the concept presented herein will work everywhere despite rapid population growth, limited financial resources, past design flaws (poor city planning, poor waste management), and current design weaknesses (poor operational management, weak institutions). In other words, rainwater storage systems should be designed and installed in cities and slums of all sizes to mitigate the effects of grey infrastructures on the water cycle. The further use of stored water for multiple purposes is obvious, including safe drinking water supply (Han & Mun 2011; Han & Nguyen 2018; Mun & Han 2012; Nandi & Gonela 2022; Kearns *et al.* 2023). Clearly, the Kilimanjaro concept enables flood mitigation even in poorly planned cities (slums) as well. A similar concept for sanitation in slums (e.g., SOIL = Sustainable Organic Integrated Livelihoods) was recently presented in Haiti (Preneta *et al.* 2013; Tilmans *et al.* 2015; Moya *et al.* 2019a, 2019b; Mallory *et al.* 2020; Carrard *et al.* 2021; Musaazi *et al.* 2023). Considering that SOIL systems solved the sanitation problem in cities and slums, the KC is regarded as the missing puzzle to achieve Goal 6 of UN Sustainable Development Goals (SDGs) during the remaining 7 years to 2030 (Hering *et al.* 2016; Krounbi *et al.* 2019; Xiao *et al.* 2023).

4. ROOTING WATER MANAGEMENT ON RWH

4.1. General aspects

The concept of IWRM as promoted today results from a segmented perspective in which available water is managed in a coordinated manner to satisfy all stakeholders and solve arising issues (Biswas 2004, 2008; Han & Nguyen 2018; Islam *et al.* 2023). As stated earlier, available water is mainly piped from aquifers or rivers. Rooting IWRM on RWH implies further equitably maximizing economic and social welfare inherent to the conventional approach while intensifying the environmental benefits (Han 2013a, 2013b; Han & Nguyen 2018; Marwa *et al.* 2018). The intensification of environmental benefits is derived from the following: (i) no or less piping network to carry water from distant rivers, (ii) less soil erosion by torrents from residential and industrial areas, and (iii) more local water infiltration and vegetation development. Moreover, public participation is a prerequisite for this approach as excess water (overflow) from each individual residence is expected in community cisterns, ponds, and tanks (Han & Nguyen 2018; Nandi & Gonela 2022; Nya *et al.* 2023). Clearly, wherever possible (e.g., rainfall data, soil structure, topography), RWH-based IWRM should secure water for drinking, ecosystem development, irrigated agriculture for food production, industrial production, livestock rearing, and all other uses (Ghisi *et al.* 2007; Kim *et al.* 2016; Kirs *et al.* 2017; Han & Nguyen 2018; Nya *et al.* 2023). The main question is how to create or protect vital ecosystems while dealing with the spatio-temporal variability of rainwater (Hasse 1989; Han 2007; Kim *et al.* 2016). Two things are certain: (i) RWH-based IWRM creates popular awareness of water management, and it makes the whole population a community of 'water managers', and (ii) RWH-based IWRM uses a local infrastructure for collection and distribution, thus avoiding water wastage due to leakage in distant supply systems (Han & Nguyen 2018; Loen 2023).

Rainwater as the main source of water for whole communities is known only on some islands where groundwater and surface water sources are polluted, limited, or simply not available (Liaw & Chiang 2014; Unsal *et al.* 2014; Kirs *et al.* 2017; Loen 2023; Parker *et al.* 2023). The common situation is that rainwater (e.g., stored in community tanks) is introduced as an alternative to conventional freshwater sources including municipal tap water, commercial bottled water, spring water, stream water, and well water (Brooks 2014; Kirs *et al.* 2017; Parker *et al.* 2023). Within this paradigm, pilot-scale studies are used to evaluate the suitability of tank rainwater, and eventually establish the conditions of its use without the risk of water-borne illnesses for the community (Han 2007; Kim *et al.* 2016; Kirs *et al.* 2017; Bak *et al.* 2020). Following this strategy, there is a broad agreement on the view that stakeholder education on (i) RWH system design options, and (ii) the importance of regular maintenance activities will secure the health of populations (Cheo 2016; Kim *et al.* 2016; Kirs *et al.* 2017; Han & Nguyen 2018; Kearns *et al.* 2023). The presentation herein takes advantage of this paradigm and acknowledges that where rainwater is polluted, methods for its treatment are available (Ghisi *et al.* 2007; Aumeier 2020; Huang *et al.* 2021b; Kearns *et al.* 2023). The remaining challenge is to convince people to use rainwater as a priority rather than a supplementary source of water (Morote-Seguido *et al.* 2020; Pembe-Ali *et al.* 2021; Nandi & Gonela 2022). It is operationally considered that this effort is financially supported as part of disaster prevention (Section 2).

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4.2. Current community-scale RWH systems

During the past 30 years or more, RWH has gained popularity in both the developed and the developing countries as a sustainable water management approach (Cheo 2016; Kim *et al.* 2016; Celik *et al.* 2017; Chirhakarhula *et al.* 2018; Lashford *et al.* 2019). Huge numbers of case studies have analysed the feasibility; water quality; and economic, social, and environmental implications of RWH in several parts of the world. However, despite existing reports on 'community-based rainwater harvesting' (Kim *et al.* 2016; Bashar *et al.* 2018; Amos *et al.* 2020; Ross *et al.* 2022; Puppala *et al.* 2023), no design concept comparable to the one described herein was found. As a rule, community tanks are tanks constructed to harvest rainwater from public buildings like churches (Brooks 2014), city halls (Ghisi 2010), commercial buildings (Sousa *et al.* 2018), hospitals (Bak *et al.* 2020; Lee *et al.* 2021), mosques (Hurayra & Rahman 2022; Kapli *et al.* 2023), schools (Kim *et al.* 2016), and universities (Almeida *et al.* 2021). This is water from relatively larger catchment areas as compared to small roofs of individual houses (Morel 1988; Laborde & Morel 1991; Brooks 2014; Cheo 2018). Residential RWH as a decentralized water supply system is considered to have the following drawbacks, making it unreliable: 'water quantities collected during the dry season are insufficient, the quality of water collected could be hazardous, and structures suffer due to a lack of expertise' (Kim *et al.* 2016). Retaining the idea of a community-based approach as a core principle, and considering the drawbacks of individual residential RWH systems, this study introduces an innovative approach in which community tanks are filled by overflows from residential tanks. This approach is regarded as an update of the cascade system of Sri Lanka (van Meter *et al.* 2014; Bhattacharya 2015), adapted to any local rural or urban architecture. The premise is that, once the community-based approach achieves a self-regulatory and transparent operating system, it will lead to predictable and sustainable water quantity and quality, achievable with more regularity and self-determination (Bhattacharya 2015; Kim *et al.* 2016).

A key feature of this approach is that harvested rainwater becomes a source of income within each community. Watermeters can measure the overflow from each residence and the corresponding monetary value, in case water is sold. Harvested rainwater can be locally used for livelihood and food security activities such as brick-making, livestock watering, or gardening. Alternatively, water from community tanks can be sold to water truckers (water trucking) for supply to communities without water or for industrial uses. On the other hand, households with water needs exceeding their harvesting capacities can buy water in the neighbourhood. Finally, in case water is not available in the neighbourhood, distant clean water can be purchased to fill the domestic tanks, for instance towards the end of the dry season when shortages can be expected (emergency water trucking). Emergency water trucking is well established as a short-term intervention that is used to cover interruptions in water service (Bradford *et al.* 2018; Sikder *et al.* 2020; van der Heijden *et al.* 2022; Lane & Kumpel 2023).

5. PATHS TO UNIVERSAL RWH

In the context of RWH to mitigate flash flood, rainfall data are needed to assess the maximum volume of water that can be harvested. Population size, number of dwellings to be supplied, and water demand in each community are not the primary goal. The intention is to minimize surface runoff while maximizing the productive uses of harvested rainwater (Han 2007; Lal 2015a, 2015b; Nya *et al.* 2023; Puppala *et al.* 2023). In other words, groundwater recharge, irrigated agriculture, and potable water supply are positive side effects of combatting flash flooding by reducing surface runoff (and not the drivers of RWH). Although the presentation is focused on residential areas, agricultural areas should also create structures (e.g., lakes, pits, ponds) to quantitatively store and infiltrate rainwater, for example, on a farm-by-farm or hill-by-hill basis.

5.1. Conceptual approach

The presentation until here has insisted on the evidence that RWH is an ancient practice that has just gained renewed attention in recent years due to its potential to address global water scarcity challenges and promote sustainable water management (Angrill *et al.* 2012; Amos *et al.* 2016; Mwamila *et al.* 2016; Alim *et al.* 2020; Amos *et al.* 2020). Figure 1 recalls that global renewable freshwater resources are finite (Lal 2015a, 2015b). These resources are also prone to eutrophication, over-exploitation, and pollution. Thus, water security is intricately and intrinsically linked to water quality and food security, and thus, food security cannot be achieved without achieving the water security and the vice versa (Lal 2015a, 2015b; Puppala *et al.* 2023). This section presents the concept of universal RWH at residential and community levels, as suggested by the Kilimanjaro concept (Marwa *et al.* 2018; Qi *et al.* 2019; Huang *et al.* 2021a). More so, the approach leads to the increased water self-sufficiency ratio (WSSR), which is the ratio of the amount of self-supplied water to total water use (Han & Kim 2007; Rygaard *et al.* 2011). The WSSR encourages a reduction in reliance on external water sources, such as rivers and

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streams, boreholes, water utilities, and vendors. The notion of WSSR suggests that RWH should be universally adopted, in cases rainwater can cover all water needs and in cases rainwater can only cover a fraction of the needs. The precipitation data (e.g., 1,400 mm/a in Bangangté, Cameroon) and the length of the dry season (e.g., 5 months in Bangangté/Cameroon) determine the storage capacity to store enough water for all-year use (Nya *et al.* 2023).

5.1.1. Residential scale RWH

Conventional sustainable water management involves technologies to (i) increase the green water storage in soil, (ii) purify the grey water, (iii) reduce the export of virtual water, (iv) increase water use efficiency, and (v) desalinize brackish water (Angrill *et al.* 2012; Liaw & Chiang 2014; Lal 2015b; Campisano *et al.* 2017). RWH is not explicitly named in this agenda although it does contribute to all five pillars, including avoiding desalination (Pembe-Ali *et al.* 2021; Nya *et al.* 2024). As stated already, the Kilimanjaro concept advocates for universal RWH, starting at the residential level.

Figure 2 shows the configuration of a typical system for domestic RWH and the interaction of its main components. Design configurations and installation protocols for RWH systems have been presented across the globe (Kim *et al.* 2016; Campisano *et al.* 2017; Nguyen & Han 2017; Dissanayake & Han 2020; Słyś & Stec 2020; Dissanayake & Han 2021). The core components of this design are the cisterns or tanks to harvest as much water as possible and the infiltration pond to enable local groundwater recharge with first flush and overflow from tanks. The main collection surface is the building rooftop, but all impervious catchment surfaces within a residence should be connected to a possibly distinct collecting tank. Mandatory devices for quality control are as follows: (i) debris screens, (ii) first flush diverters, and (iii) filters (Abbasi & Abbasi 2011). A critical point of this design is that the overflow from the tanks should be directed to a community reservoir or tank. In some cases, especially in low-income regions, where (daily) rainfall data for the design of RWH systems are limited or lacking, reasonable design approaches have been introduced (Jung *et al.* 2015; Nguyen & Han 2017; Cheo 2018; Abas & Mahlia 2019; Semaan *et al.* 2020).

In addition, at a residential scale, harvesting impact can be evaluated collectively. If all households can embark on harvesting volumes of rainwater equivalent to what is occupied by the respective building infrastructures, that will control surface runoff as well as address dry season water supply challenges. For instance, for a household with a 100 m^2 metal roof ($C = 0.8$ in Equation (2)), in a day receiving 100 mm of rainfall, a runoff volume of approximately 8,000 L is produced, which

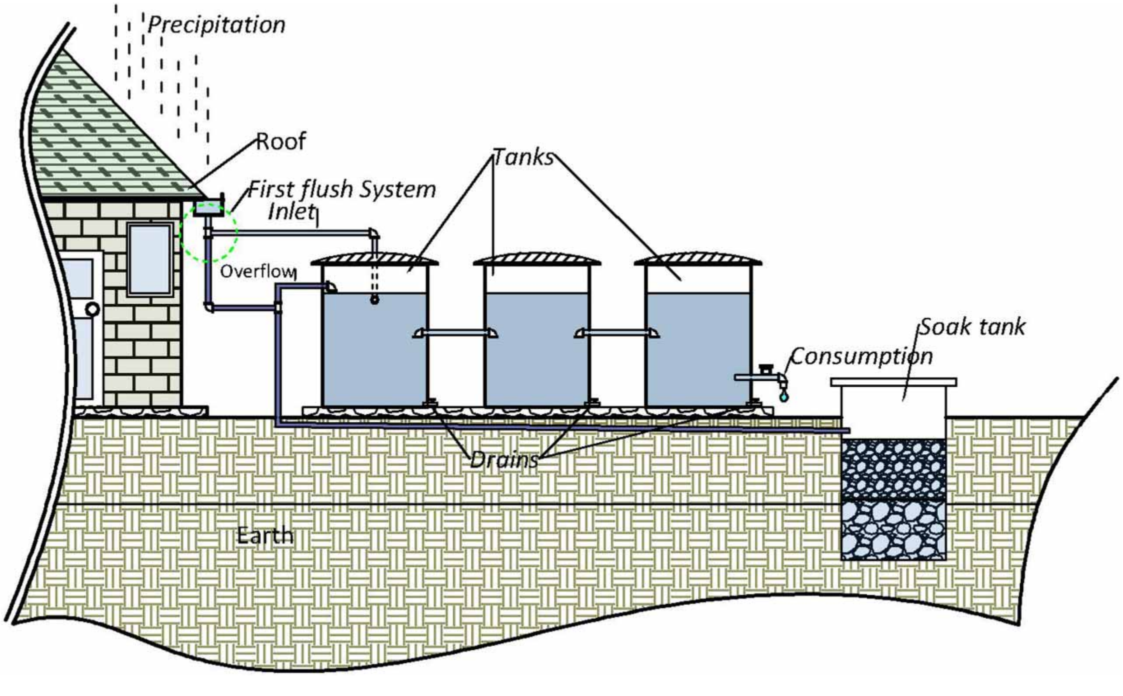

Figure 2 | Components of a typical rainwater harvesting system at household level. Arrows indicate water fluxes. The first flush is directly collected in the infiltration pit. NRV stands for non-return valve.

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prior to the building construction would have spatially infiltrated into the soil, a fraction of it ponded, some of it evaporated and the rest of it is runoff. If it were only one household, then there is not much to worry about as the impact would be insignificant. However, there are several houses simultaneously discharging similar quantities of water towards areas which do not have proper stormwater management plan, subsequently the discharge of large volumes of surface runoff from the said houses tends to flood and destroy the surrounding environment in that particular time. Receiving water bodies such as River Tegeta, River Msimbazi in Dar es Salaam Tanzania, whose performance is already hampered by the introduction of household waste continuously dumped on it, is expected to not only receive but also contain this excess runoff water. With such rivers overwhelmed and failing to handle the excess rainwater, the outcome is the floods experienced in most parts of our African cities. There is a need to be proactive, change mindset (paradigm shift), and exploit available resources towards sustainable development. For example, the said runoff generated volume of 8,000 L if harvested could serve the daily demand of 80 people at 100 L per person per day. Thus, dry season water shortage problems are actually solvable. '*Harvest water during the rainy season, safely store it, and use it during the dry season*' should be the motto.

Water supply primarily using RWH requires well-established operation and maintenance (O & M) systems for their sustainability at both household and community levels (Słyś & Stec 2020; MacAllister *et al.* 2022). This means that each community owns and manages (or has affordable access to) all water management services. This requires that the management, operation, and maintenance of facilities are done by the users themselves, while public health authorities control water quality at all levels. In this model, users cover costs related to the installation, operation, and maintenance and after-life replacement of all components of their RWH systems. Operation and maintenance can be managed by a well-trained team (team of caretakers) according to norms fixed by the administration, for example, each residential tank should be cleaned yearly by the team or under its supervision. This approach could create jobs for some members of the community while making sure that older members are not left alone with maintenance operations. Therefore, there is a need to set affordable tariffs for all O & M operations. It is recalled that subsidies must be made available, at least for community tanks because it is about disaster prevention (Section 2).

5.1.2. Community-scale RWH

Figure 3 shows the configuration of an innovative system for collecting overflows from residential RWH systems (a cluster of four residences). Figure 4 shows a community-scale water reservoir with a water treatment station and an infiltration device (e.g., pond and well). This also accommodates water demand scenarios of industries, commercial complexes, bus stops (e.g., Dar es Salaam Rapid Transport stands), public office structures, and hotels. These facilities may transform from full reliance on RWH to centralized supply systems to being self-sufficient, relying on multiple sources (e.g. RWH from own large roofs, in-home impervious surfaces), and partly centralized (if need remains). Sadly, in most of these structures/facilities, the current practice is to drain rainwater, and it is speedily facilitated with the presence of paved areas, and in most cases, a plastic cover is laid beneath the pavers, thus pavers lie on plastic (thus, resulting in 100% inhibition of rainwater water seepage).

5.1.3. Sizing the tanks

A fundamental question to answer while installing the RWHI is: What is the appropriate size of the tank? Usually, calculations are made to satisfy the immediate needs of a stakeholder. For example, a person using harvested rainwater for garden maintenance and necessitating 250 L/day for 100 dry days needs to store 25,000 L or 25 m^3 of water per year. For this person, it suffices to build a tank with a capacity of 25 m^3 or buy five rainwater barrels at 5 m^3. (The capacity of each barrel is 5 m^3). In a second example, a family of five members, using each 25 L water per day needs $5 \times 25 \times 365 = 54{,}750$ L water per year. That is, some 55 m^3 of water per year. This question in this work is: Can this family cover his whole year water supply while using harvested rainwater alone? In case there is excess how to use it? In case of deficit, where from to have the needed water volumes?

The calculations in Section 5.1.1 were for 100 mm of rain falling on a roof area of 100 m^2 and giving a runoff volume of 8,000 L (8 m^3). The only assumption was a runoff coefficient of 0.8 (80% of rainfall is effectively collected). This means that 8 m^3 of water can potentially be harvested from 100 mm of rainfall in Dar es salaam (Tanzania), Göttingen (Germany), Maroua (Cameroon), Postdam (Germany), and Tlemcen (Algeria). The chosen cities correspond to the affiliations of the authorship of this article. The named cities correspond to four different climatic zones: (i) Mediterranean (Tlemcen), (ii) semi-arid (Maroua), (iii) temperate (Göttingen and Postdam), and (iv) tropical (Dar es salaam). Each climate zone is characterized by its annual average temperature (and precipitation). The average temperature is the key parameter controlling the evaporation, E values in Equation (1) (Table 1). Normally extreme temperatures should be considered because it is about

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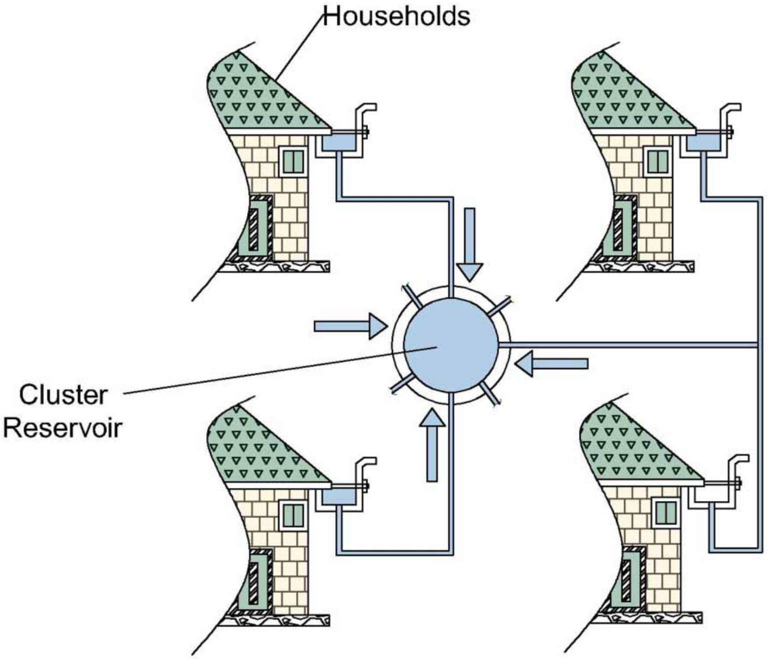

Figure 3 | Rainwater harvesting at the cluster level.

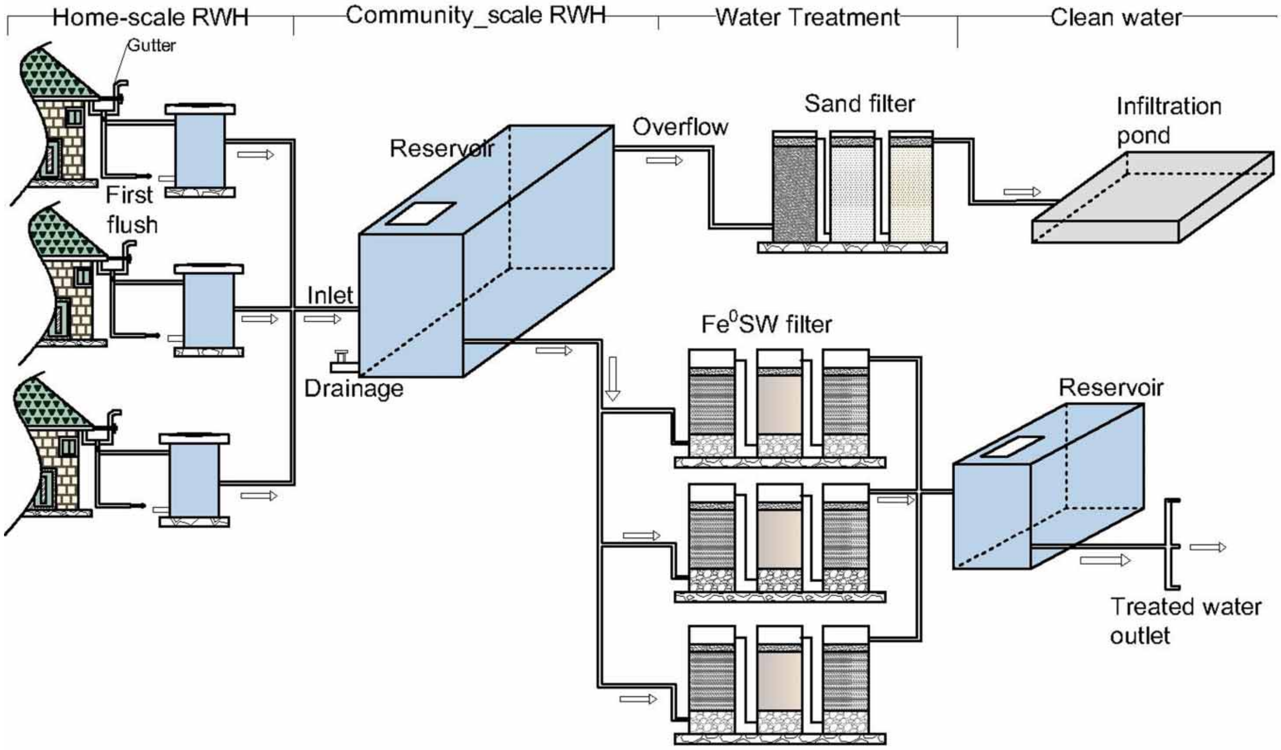

Figure 4 | Configuration of a community rainwater harvesting system with a water treatment station. Community-scale water reservoirs are designed to collect overflows from cisterns and tanks from individual households and farms. Overflow from the community tank is directed to infiltration devices (e.g., ponds and wells). Fe^0 SW filter represents a sand filter amended with steel wool (Fe^0 SW) (Nya *et al.* 2023).

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Table 1 | Total amount of rainwater (m^3/a) harvestable from a 100 m^2 roof at five selected locations

Locality	Temperature (°C)	Precipitation (mm/a)	Water (m^3/a)	Coverage (%)
Dar es Salaam	26.6	1,150.0	92.0	+67
Göttingen	9.4	587.1	47.0	–15
Maroua	28.7	726.2	58.1	+6
Postdam	9.4	618.0	49.4	–10
Tlemcen	15.4	454.0	36.3	–34

Note: 'Coverage' indicates the extent to which the water needs of a five-member family (55 m^3/a) is covered. '+' stands for excess and '–' for deficit.

evaporation. For example, the driest days in Maroua correspond to temperatures averaging 40 °C, while 30 °C is scarce in Dar es salaam. This is the main reason why harvested rainwater should be stored in a (buried and) closed tank.

Table 1 shows clearly that, if the harvested water should satisfy the needs of the five-member family (55 m^3 per year), a 100 m^2 roof is sufficient only in Dar es Salaam (67% excess) and Maroua (6% excess). The three other cities have to increase the catchment area (roof area > 100 m^2) or find alternative water sources (e.g., piped water, springs, wells). The premise of this work is that harvesting rainwater lowers the competition for alternative freshwater sources while protecting the environment and creating new opportunities (Henriquez 1962; van Buurt 2018; Nya *et al.* 2023). In this perspective, recycling domestic wastewater is regarded as the first option to compensate for the deficit in Göttingen, Postdam, and Tlemcen.

Coming back to tank sizing, a rule of thumb corresponding to the motto 'harvest it when you can' is to capture and store (and partially infiltrate) the whole year's rain falling on roots. In the concept presented herein, community tanks are a sort of buffer to consider the evidence that individual households have different water uses (e.g., family size, diverse activities) and eventually undersized residential tanks. Community tanks also store water from extraordinary events like very heavy rains allowing high amounts of water to escape from the conveyance system of the RWHI. Table 1 shows that, under similar conditions of demand, in low rainfall areas, one may need larger storage tanks and/or larger catchment areas to ensure water is available to serve demand for a longer period, unlike in high rainfall areas. However, 'harvest it when you can' commands that even in high rainfall areas, larger storage tanks should be used, and excess water is used for productive activities like brick-making during the rainy season. Taking the example of Dar es Salaam (Figure 5), such water-consuming activities can be planned for the period corresponding to days 70–130 (60 days or 2 months). Depending on the weather forecast, community tanks can be emptied during this period when heavy rains are expected. In other words, without complex drainage systems, the KC can be exploited to avoid flash floods.

5.2. Centralized or decentralized RWH systems

Conventionally, there are two approaches for rainwater management: centralized and decentralized systems (Sharma *et al.* 2010; Domènech 2011; Domènech & Saurí 2011; Younos 2011; Vallés-Casas *et al.* 2016; Słyś & Stec 2020; Richards *et al.* 2022; Kalbar & Lokhande 2023; Puppala *et al.* 2023; Soh *et al.* 2023). In centralized management systems, rainwater from several roofs, green areas, or traffic areas is collected/drained and stored or infiltrated into community reservoirs (e.g., cisterns, tanks) or infiltration plants (e.g., basins, ditches) (Angrill *et al.* 2012). In decentralized rainwater management, rainwater from individual, small-scale roofs, traffic areas, and green areas is managed or seeped away at the point of origin (e.g., farm, household) (Angrill *et al.* 2012). The innovative approach suggested herein strives to drain only excess water from small-scale reservoirs and store/infiltrate it at a community scale. In essence, it corresponds to a centralized system, with the subtle but key difference that each point of origin (e.g. farm, residence) is a water production unit for all uses (including drinking water). Clearly, RWH is made 'everyone's issue'. Making RWH everyone's issue corresponds to several known slogans including: (i) 'cash it when you can' (Durodola *et al.* 2020) and (ii) 'use rainwater instead of dispose it' (Gueldenberg 1998).

The Kilimanjaro concept advocates for universal decentralized drinking water treatment at the household level, whether centralized systems are likely to be accessible and reliable. Fortunately, versatile household-based water treatment processes to cope with eventually polluted rainwater are available (Alsulaili *et al.* 2020; Huang *et al.* 2021b; Kearns *et al.* 2023). Such processes (i) depict a minimum dependence on supply of spare parts, (ii) are typically easy to operate and maintain, and (iii) use locally available materials (e.g., biochar, metallic iron) and skills (Banerji & Chaudhari 2017; Aumeier 2020; Huang *et al.*

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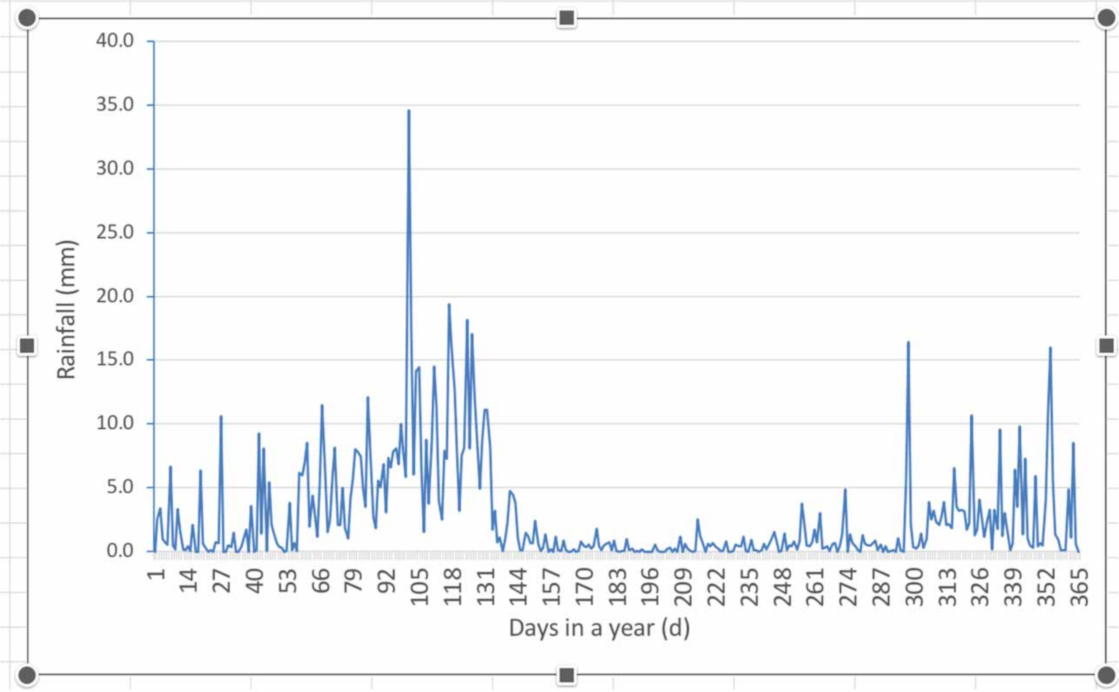

Figure 5 | Average daily rainfall data 2009–2018 for Dar es Salaam, Tanzania (*Data Source*: Tanzania Meteorological Agency).

2021b; Kearns *et al.* 2021; Kearns *et al.* 2023). Several water treatment processes fulfil the aforementioned requirements and have demonstrated their technical feasibility in self-sustaining operation at household level (Aumeier 2020; Tepong-Tsindé 2021; Richards *et al.* 2022; Kearns *et al.* 2023). In other words, the Kilimanjaro concept potentially safeguards access to universal safe drinking water (fundamental human right) and protects millions of people from flash flooding worldwide.

5.3. The Kilimanjaro concept and 'the tragedy of the commons'

'The tragedy of the commons' is a relatively old metaphor that has motivated the discussion on the rationale use of natural resources over the past five decades (Hardin 1968; Ostrom 1996, 2000; Araral 2014; Ponte *et al.* 2021; Cashore & Bernstein 2023). The tragedy of the commons considers that a common pool of not privately owned natural resources is prone to failure, misuse, and ruin. Within the water supply community for low-income settings, the named metaphor is mostly used to sustain the discussion on the willingness to pay for water services (Whittington *et al.* 2012; Akkerman 2020; Nya *et al.* 2023).

The tragedy of the commons can be considered for community tanks as discussed herein (Section 5.1.2). However, water flowing into such tanks comes from individual residential tanks (overflows) (Figure 3). The driving force of the KC is that the rational man will prefer to have his own water at home before releasing the excess into the community tanks (Akkerman 2020; Nya *et al.* 2023). Assuming that this is true for everyone, the remaining challenge is to find the best way to equip individual residences with well-sized and operating RWHIs. Once RWHIs are made available, people can even commercialize water they have harvested or use it for productive activities (Han 2023a, 2023b; Nya *et al.* 2023).

The other evidence is that rainwater is perhaps the sole natural resource that is automatically wasted when it is not harvested. As discussed in Section 2, RWH has several economic, environmental, and social benefits. This is because it is rather the non-harvesting of rainwater that is linked to damages (e.g., erosion, flood, water contamination via leaching of wastes). In other words, encouraging RWH has no potential harm but only has benefits for human and ecology.

The KC is an attempt to create centralized RWHIs at a neighbourhood level. This means that no outsiders to the neighbourhood have access to the harvested water. However, among community members, rules are needed for the systems to be effective. Such rules shall be elaborated, known, understood, and revised to cope with changing conditions. It is certain

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that each community can find effective and sustainable management rules for the common locally harvested rainwater. As pointed out by Nya *et al.* (2023) the state through the municipality should supervise quality control of harvested rainwater and makes sure that appropriate treatment technologies are applied where the water is used as potable water. To ease this task, equipped and accredited laboratory should be made available and citizens train to ask for controlled safe drinking water (Ogisma 2022).

6. TOWARDS A NEW ECONOMIC ERA WITH RWH?

Households without access to piped water or relying on a private water source are considered water-poor. Such households are mainly in areas of high elevation or scattered settlements (Domènech *et al.* 2012; Heijnen 2013; Biswas & Mandal 2014; Cassivi *et al.* 2023). In the developed world, there are efforts to support their access to piped water or at least to make sure that residents receive some form of safe drinking water (Bradford *et al.* 2018; Anderson *et al.* 2023; Balasooriya *et al.* 2023; Cassivi *et al.* 2023). Following the conventional approach, the problem is that connecting to mains water is typically expensive and the costs fall on individuals. An alternative approach has been to let people have their private water supply systems while ensuring the responsibility for the water quality (Domènech 2011; Vallés-Casas *et al.* 2016; Alsulaili *et al.* 2020; Kalbar & Lokhande 2023). Although privately ensuring the water quality can be regarded as an additional burden or an injustice, it has been a viable approach in many cases (Murphy *et al.* 2010; Scalley 2012; Kalbar & Lokhande 2023; Loen 2023). Within the framework of the Kilimanjaro concept, the responsibility for making the water potable falls clearly on individual households, however, under strong public control (Nya *et al.* 2023). For this reason, municipalities are invited to create or promote the creation of accredited water laboratories (Reijtenbagh 2010; Ogisma 2022; Loen 2023; Nya *et al.* 2023). In other words, RWH is an optimal solution for water supply everywhere there is rainfall: (i) in the valley and at higher elevations, (ii) in humid and semi-arid regions, and (ii) in rural and urban areas. Depending on the abundance of rain, RWH can be either (i) a stand-alone technology for water supply or (ii) a supplementary amount of water supplied by other sources, which have been considered to be conventional (e.g. rivers, springs, wells). On a very local scale, RWH has two main advantages: (i) wells are more productive (more water available via artificial recharge) and (ii) the demand for well water has decreased (water conservation).

6.1. Economic implications of large-scale RWH adoption

The soundest foundation of human health and prosperity is universal access to a safe drinking water supply (UN SDG 6.1) (Hering *et al.* 2016). Historical evidence from the Dutch Caribbean (e.g., Bonaire, Curaçao, Saba, St. Eustatius) and from South-East Asia (India, Korea, Sri Lanka) demonstrates that large-scale, self-reliance water management rooted in RWH is applicable and very efficient (Henriquez 1962; Dharmasena 1994; Han 2013a; van Meter *et al.* 2014; Loen 2023). The affordability of such decentralized systems has been discussed (Musz-Pomorska *et al.* 2020; Nya *et al.* 2023). However, it is certain that their design can be regarded as low-tech compared to piping and treating water from distant rivers. The merit of such systems is that they correspond to the paradigm 'small is beautiful' (Schumacher 1973) and are a powerful tool to achieve a 'circular economy' (Bauwens *et al.* 2020; Friant *et al.* 2020; Giampietro & Funtowicz 2020). Large-scale RWH adoption can have significant economic implications for both the supply and demand sides of water resources management (Cook 2004; Heijnen 2013).

- On the supply side, RWH reduces the dependence on conventional sources of water, such as surface water and groundwater, which are often scarce, expensive, and vulnerable to climate change. RWH can reduce the need for costly water infrastructure, such as dams, pipelines, treatment plants, and pumping stations, which require high capital investment, operation and maintenance costs, and energy consumption. RWH also reduces the environmental impacts of water extraction and distribution, such as land degradation, biodiversity loss, water pollution, and greenhouse gas emissions.
- On the demand side, RWH can increase the availability and accessibility of water for various uses, especially in rural and peri-urban areas where water services are often inadequate or unreliable. RWH improves the quality and quantity of water for agricultural production, which can enhance food security, income generation, and livelihood diversification. RWH can also improve the quality and quantity of water for domestic use, which can improve health, hygiene, sanitation, and gender equity. RWH also provides a buffer against droughts and floods, which can reduce the vulnerability and resilience of communities to climate shocks.

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6.2. Potential benefits to local economies

Large-scale RWH adoption can generate multiple benefits to local economies in terms of value creation, cost savings, income generation, employment creation, and social welfare (Henriquez 1962; Domènech *et al.* 2012; Heijnen 2013; Naval 2016). It can also increase the availability and accessibility of water for various uses and provide a buffer against climate shocks. Some of benefits of large-scale RWH are quantifiable and measurable, while others are qualitative and intangible. The present article presented a qualitative conceptual framework for mitigating floods in cities via RWH. The quantities of harvestable rainwater, the demand met via RWH, and the extent of flood mitigation will invariably differ among cities. Therefore, further work is required to pilot-test and to validate the conceptual framework in typical urban settings.

Table 2 summarizes some of the potential benefits to local economies from RWH adoption.

6.3. Recommendations

In light of the foregoing, the following recommendations are made:

- Embrace universal rainwater harvesting (RWH) implementation: To address global water scarcity challenges and promote sustainable water management, governments should proactively encourage universal RWH. Financial incentives should be offered to individuals and communities to invest in RWH infrastructure. Mandatory laws can be passed, requiring RWH in new construction sites to make RWH a norm rather than an exception. By fostering collaboration with public and private sectors, RWH initiatives can be further accelerated, making it an integral part of national and regional water management policies.
- Raise awareness through public education campaigns: Effective public education campaigns are crucial to raise awareness about the benefits of RWH. Governments, NGOs, and communities must join forces to educate the public on how RWH can mitigate flash floods, provide an alternative water source during droughts, and contribute to overall water conservation. Integrating RWH education into curricula can instil a culture of water conservation from an early age, ensuring a generation that values water as a precious resource.
- Strengthen public–private partnerships: Public–private partnerships play a pivotal role in driving innovation and making RWH technology more cost-effective. Governments must collaborate with the private sector to advance RWH technology while ensuring policy integration of national and regional water management policies. By establishing favourable provisions and regulations supporting RWH adoption, the private sector can work hand in hand with governments to make RWH initiatives seamless.
- Capacity building and technical advancements: NGOs can play a crucial role in promoting RWH in communities through capacity building and technical approaches. Local communities should be empowered through training programs and workshops, ensuring they have the necessary skills, knowledge, and financial support to successfully implement and sustain RWH initiatives. Investing in research and advancements, such as sensor-based control systems and hybrid water supply management, can enhance the efficiency and reliability of RWH systems, making them even more effective in mitigating flash floods and conserving water.

Table 2 | Potential benefits to local economies from RWH adoption

Benefits	Description	Example
Value creation	The economic value of water that is harvested and used for beneficial purposes	The value of crop production from irrigated rainwater
Cost savings	The reduction in costs associated with water supply or demand	The reduction in water bills or energy costs from using harvested rainwater
Income generation	The increase in income from selling products or services that use harvested rainwater	The income from selling vegetables or flowers grown with harvested rainwater
Employment creation	The increase in employment opportunities from activities related to RWH	The jobs created from installing or maintaining RWH systems
Social welfare	The improvement in social indicators such as health, education, gender equality, and poverty reduction	The improvement in child mortality or school attendance from using harvested rainwater

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7. CONCLUDING REMARKS

Adoption of RWH on a global scale would pave the way for sustainable water management and offer a solid remedy for issues like flash floods and water scarcity. Governments, NGOs, and communities can work together to make RWH the norm, ensuring a better, more secure future for water management. Societies can adopt RWH and benefit from its many advantages by providing financial incentives, enacting legislation that is required, and promoting awareness through public education initiatives.

A major economic impact on both the supply and demand sides of water resource management would result from the widespread use of RWH. RWH lessens environmental effects, lowers capital investment in water infrastructure, and lowers operational costs by lowering reliance on conventional water sources. On the demand side, RWH expands the amount of water that is available for domestic and agricultural usage, improving food security, income production, and general well-being. RWH adoption becomes both a necessity for the environment and a competitive advantage for local economies as a result of the value creation, cost savings, revenue production, and employment opportunities it generates. Therefore, RWH can continue to develop as a potent weapon to address water scarcity and enhance water management practices with a dedication to research and technological developments. Societies may build sustainable water systems that protect against climate shocks and enable a more prosperous future by establishing water management on RWH and incorporating it into wider water management frameworks.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Abas, P. E. & Mahlia, T. M. I. 2019 Techno-economic and sensitivity analysis of rainwater harvesting system as alternative water source. *Sustainability* **11**, 2365.

Abbasi, T. & Abbasi, S. A. 2011 Sources of pollution in rooftop rainwater harvesting systems and their control. *Crit. Rev. Environ. Sci. Technol.* **41**, 2097–2167.

Adams, W., Brun, C. & Havnevik, K. 2010 Studies of the waterscape of Kilimanjaro, Tanzania: Water management in hill furrow irrigation. *Norsk Geografisk Tidsskrift-Norwegian J. Geogr.* **64**, 172–173.

Agarwal, A. & Narain, S. 1999 *Making Water Management Everybody's Business: Water Harvesting and Rural Development in India*. International Institute for Environment and Development. Available from: https://www.jstor.org/stable/resrep01729 (Accessed 7 May 2023).

Akkerman, P., 2020 The Calabash Cistern 5000 L in Africa. In: *International Rainwater Catchment Systems Experiences: Towards Water Security* (Espíndola, J. A. G., Flores, C. A. C., Pacheco-Vega, R. & Montes, M. R. P. eds.). IWA Publishing 2020, London UK. doi:10.2166/9781789060584_0229.

Ako Ako, A., Nzali, C. T., Lifongo, L. L. & Nkeng, G. E. 2022 Rainwater harvesting (RWH): a supplement to domestic water supply in Mvog-Betsi, Yaoundé-Cameroon. *Water Supply* **22**, 1141–1154.

Alim, M. A., Rahman, A., Tao, Z., Samali, B., Khan, M. M. & Shafiq Shirin, S. 2020 Suitability of roof harvested rainwater for potential potable water production: A scoping review. *J. Clean. Prod.* **248**, 119226.

Almeida, A. P., Liberalesso, T., Silva, C. M. & Sousa, V. 2021 Dynamic modelling of rainwater harvesting with green roofs in university buildings. *J. Clean. Prod.* **312**, 127655.

Alsulaili, A., Al-Harbi, M. & Elsayed, K. 2020 The influence of household filter types on quality of drinking water. *Process Saf. Environ. Prot.* **143**, 204–211.

Amos, C. C., Rahman, A. & Gathenya, J. M. 2016 Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya. *Water* **8**, 149.

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Amos, C. C., Rahman, A. & Gathenya, J. M. 2018 Economic analysis of rainwater harvesting systems comparing developing and developed countries: A case study of Australia and Kenya. *J. Clean. Prod.* **172**, 196–207.

Amos, C. C., Ahmed, A. & Rahman, A. 2020 Sustainability in water provision in rural communities: The feasibility of a village scale rainwater harvesting scheme. *Water Resour. Manage.* **34**, 4633–4647.

Anchan, S. S. & Prasad, H. C. S. 2021 Feasibility of roof top rainwater harvesting potential – A case study of South Indian University. *Clean. Eng. Technol.* **4**, 100206.

Anderson, H. K., Price, H. & Staddon, S. 2023 Water poverty in a 'Hydro Nation': Exploring distributional and recognitional water injustices in Scotland. *Utilities Policy* **85**, 101679.

Angrill, S., Farreny, R., Gasol, C. M., Gabarrell, X., Viñolas, B., Josa, A. & Rieradevall, J. 2012 Environmental analysis of rainwater harvesting infrastructures in diffuse and compact urban models of Mediterranean climate. *Int. J. Life Cycle Assess.* **17**, 25–42.

Araral, E. 2014 Ostrom, Hardin and the commons: A critical appreciation and a revisionist view. *Environ. Sci. Pol.* **36**, 11–23.

Aumeier, B. M. 2020 *The Hydrothermal Solution for Decentralized Drinking Water Purification*. PhD Dissertation, Rheinisch-Westf ̈alischen Technischen Hochschule Aachen, Germany.

Bak, G., Dao, A. D. & Han, M. 2020 Improving the hydrological performance of a rainwater for drinking (RFD) system at a rural hospital in Vietnam. *J. Water Sanit. Hyg. Dev.* **10**, 916–926.

Balasooriya, B. M. J. K., Rajapakse, J. & Gallage, C. 2023 A review of drinking water quality issues in remote and indigenous communities in rich nations with special emphasis on Australia. *Sci. Total Environ.* **903**, 166559.

Banerji, T., Chaudhari, S., 2017 A cost-effective technology for arsenic removal: Case study of zerovalent iron-based IIT Bombay arsenic filter in West Bengal. In: *Water and Sanitation in the New Millennium* (Nath, K. & Sharma, V. eds.). Springer, New Delhi, pp.127–137.

Bashar, M. Z. I., Karim, M. R. & Imteaz, M. A. 2018 Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh. *Resour. Conserv. Recycl.* **133**, 146–154.

Bauwens, T., Hekkert, M. & Kirchherr, J. 2020 Circular futures: What will they look like? *Ecol. Econ.* **175**, 106703.

Bensi, N. S., 2020 The qanat system: A reflection on the heritage of the extraction of hidden waters. In: *Adaptive Strategies for Water Heritage* (Hein, C. ed.). Springer Nature Switzerland AG, Cham, Switzerland, pp. 41–58.

Bhattacharya, S. 2015 Traditional water harvesting structures and sustainable water management in India: A socio-hydrological review. *Int. Lett. Nat. Sci.* **37**, 30–38.

Biswas, A. K. 2004 Integrated water resources management: A reassessment: A water forum contribution. *Water Int.* **29**, 248–256.

Biswas, A. K. 2008 Integrated water resources management: Is it working? *Int. J. Water Resour. Dev.* **24**, 5–22.

Biswas, B. K. & Mandal, B. H. 2014 Construction and evaluation of rainwater harvesting system for domestic use in a remote and rural area of Khulna, Bangladesh. *Int. Sch. Res. Notices* **14**, 751952.

Bradford, L., Waldner, C., McLaughlin, K., Zagozewski, R. & Bharadwaj, L. 2018 A mixed-method examination of risk factors in the truck-to-cistern drinking water system on the Beardy's and Okemasis First Nation Reserve, Saskatchewan. *Canadian Water Resour. J.* **43**, 383–400.

Brooks, J. 2014 Failure and potential: Rainwater harvesting in a rural, mountainous Haitian village. *Trop. Resour. Bull* **32–33**, 56–62.

Brown, R. R., Keath, N. & Wong, T. H. F. 2009 Urban water management in cities: Historical, current and future regimes. *Water Sci. Technol.* **59**, 847–855.

Bui, T. T., Nguyen, D. C., Han, M., Kim, M. & Park, M. 2021 Rainwater as a source of drinking water: A resource recovery case study from Vietnam. *J. Water Proc. Eng.* **39**, 101740.

Cain, N. L. 2014 A different path: The global water crisis and rainwater harvesting. *Consilience* **12**, 147–157.

Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., Fisher-Jeffes, L. N., Ghisi, E., Rahman, A., Furumai, H. & Han, M. 2017 Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water Res.* **115**, 195–209.

Carrard, N., Jayathilake, N. & Willetts, J. 2021 Life-cycle costs of a resource-oriented sanitation system and implications for advancing a circular economy approach to sanitation. *J. Clean. Prod.* **307**, 127135.

Cashore, B. & Bernstein, S. 2023 Bringing the environment back in: Overcoming the tragedy of the diffusion of the commons metaphor. *Perspect. Politics* **21**, 478–501.

Cassivi, A., Covey, A., Rodriguez, M. J. & Guilherme, S. 2023 Domestic water security in the Arctic: A scoping review. *Int. J. Hyg. Environ. Health* **247**, 114060.

Celik, I., Tamimi, L. M., Al-Khatib, I. A., Al-Khatib, I. A. & Apul, D. S. 2017 Management of rainwater harvesting and its impact on the health of people in the Middle East: Case study from Yatta town, Palestine. *Environ. Monit. Assess.* **189**, 271.

Cheo, A. E. 2016 Understanding seasonal trend of rainfall for the better planning of waterharvesting facilities in the Far-North region, Cameroon. *Water Util. J.* **13**, 3–11.

Cheo, A. E. 2018 *Integrated Water Resources Management (IWRM): The Case Study of the Far-North Region, Cameroon*. PhD Dissertation, Brandenburg University of Technology, Cottbus-Senftenberg, Germany.

Chirhakarhula, E. C., Harriet, W., John, W. E. & Kirstin, E. R. 2018 A review of roof harvested rainwater in Australia. *J. Environ. Public Health* **2018**, 1–14.

Chitata, T., Kemerink-Seyoum, J. S. & Cleaver, F. 2021 Engaging and learning with water infrastructure: Rufaro Irrigation Scheme, Zimbabwe. *Water Alternatives* **14**, 690–716.

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Chopin, T. & Jamet, J.-F. 2016 The Future of Europe. Robert Schuman Foundation, European Issues 402, 13th September 201. Available from: https://www.robert-schuman.eu/en/european-issues/0402-the-future-of-europe (accessed 20 September 2023).

Cook, G. C. 2001 Construction of London's Victorian sewers: The vital role of Joseph Bazalgette. *Postgrad. Med. J.* **77**, 802–804.

Cook, S. 2004 Assessing the achievements and problems of rural resource management programs in western China: A case study from Gansu Province, China. *Environ. Series* **7**, 55–60.

Cristiano, E., Farris, S., Deidda, R. & Viola, F. 2023 How much green roofs and rainwater harvesting systems can contribute to urban flood mitigation? *Urban Water J.* **20**, 140–157.

Dallman, S., Chaudhry, A. M., Muleta, M. K. & Lee, J. 2016 The value of rain: Benefit-cost analysis of rainwater harvesting systems. *Water Resour. Manage.* **30**, 4415–4428.

Dallman, S., Chaudhry, A. M., Muleta, M. K. & Lee, J. 2021 Is rainwater harvesting worthwhile? A benefit–cost analysis. *J. Water Resour. Plan. Manage.* **147**, 04021011.

Davis, F. 1891 *An Elementary Handbook on Potable Water*. Silver, Burdett & Co, New York, Boston, Chicago/USA, p. 118.

de Assis Matos de Abreu, F., Duarte, A. M., Ribeiro, M. R., de Lima, A. R. C. & de Jesus Sousa, W. 2005 The hydrologic cycle: An open or a closed system? *Revista Geográfica* **137**, 109–122.

Demeke, B. W. & Amali, A. A. 2023 Exploring the contribution of rooftop rainwater harvesting as an integral component of the urban water mix. In: *Water Security and Cities: Integrated Urban Water Management* (UNESCO and i-WSSM, Choi S. H., Shin E., Kim D., Song Y., Zandaryaa S., Makarigakis A. K., Kim J.-y. Sohn O., Clench C. & Trudeau M. eds). Global Water Security Issues (GWSI) Series, Issue No. 4, UNESCO Publishing, Paris/France.

Dharmasena, P. B. 1994 Conservation farming practices for small reservoir watersheds: A case study from Sri Lanka. *Agrofor. Syst.* **28**, 203–212.

Dijk, S., Lounsbury, A. W., Hoekstra, A. Y. & Wang, R. 2020 Strategic design and finance of rainwater harvesting to cost-effectively meet large-scale urban water infrastructure needs. *Water Res.* **184**, 116063.

Dissanayake, J. & Han, M. 2020 Effect of inlet/outlet configuration on water quality in a rainwater harvesting tank. *Water* **12**, 1970.

Dissanayake, J. & Han, M. 2021 The effect of number of tanks on water quality in rainwater harvesting systems under sudden contaminant input. *Sci. Tot. Environ.* **769**, 144553.

Domènech, L. 2011 Rethinking water management: From centralised to decentralised water supply and sanitation models. *Documents D'Anàlisi Geogràfica* **57**, 293–310.

Domènech, L. & Saurí, D. 2011 A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the metropolitan area of Barcelona (Spain): Social experience, drinking water savings and economic costs. *J. Cleaner Prod.* **19**, 598–608.

Domènech, L., Heijnen, H. & Saurí, D. 2012 Rainwater harvesting for human consumption and livelihood improvement in rural Nepal: Benefits and risks. *Water Environ. J.* **26**, 465–472.

Durodola, O. S., Bwambale, J. & Nabunya, V. 2020 Using every drop: Rainwater harvesting for food security in Mbale, Uganda. *Water Pract. Technol.* **15**, 295–310.

Echendu, A. J. 2020 The impact of flooding on Nigeria's sustainable development goals (SDGs). *Ecosyst. Health Sust.* **6**, 1791735.

Echendu, A. J. 2022 Flooding in Nigeria and Ghana: Opportunities for partnerships in disaster-risk reduction. *Sustainability Sci. Pract, Pol.* **18**, 1–15.

Eckart, K., McPhee, Z. & Bolisetti, T. 2018 Multiobjective optimization of low impact development stormwater controls. *J. Hydrol.* **562**, 564–576.

Egbinola, C. N., Olaniran, H. D. & Amanambu, A. C. 2017 Flood management in cities of developing countries: The example of Ibadan, Nigeria. *J. Flood Risk Manage.* **10**, 546–554.

Faragò, M., Brudler, S., Godskesen, B. & Rygaard, M. 2019 An eco-efficiency evaluation of community-scale rainwater and stormwater harvesting in Aarhus, Denmark. *J. Clean. Prod.* **219**, 601–612.

Farreny, R., Morales-Pinzón, T., Guisasola, A., Tayà, C., Rieradevall, J. & Gabarrell, X. 2011 Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. *Water Res.* **45**, 3245–3254.

Ferreira, A., Santos, C., Imteaz, M. A. & Matos, C. 2023 Hybrid decentralized systems of non-potable water supply: Performance and effectiveness analysis. *Water Resour. Manage.* **37**, 3897–3919.

Fioramonte, B., Campos, M. A. S., de Freitas, S. R. & Basso, R. E. 2022 Rainfall data used for rainwater harvesting systems: A bibliometric and systematic literature review. *AQUA – Water Infrastr. Ecosyst. Soc.* **71**, 816–834.

Fonseca, C. R., Hidalgo, V., Díaz-Delgado, C., Vilchis-Francés, A. Y. & Gallego, I. 2017 Design of optimal tank size for rainwater harvesting systems through use of a web application and geo-referenced rainfall patterns. *J. Clean. Prod.* **145**, 323–335.

Freni, G. & Liuzzo, L. 2019 Effectiveness of rainwater harvesting systems for flood reduction in residential urban areas. *Water* **11**, 1389.

Friant, M. C., Vermeulen, W. J. & Salomone, R. 2020 A typology of circular economy discourses: navigating the diverse visions of a contested paradigm. *Resour. Conserv. Recycl.* **161**, 104917.

Fu, G., Butler, D., 2021 Pathways towards sustainable and resilient urban water systems. In: *Water-Wise Cities and Sustainable Water Systems: Concepts, Technologies, and Applications* (Wang, X. C. & Fu, G. eds.). IWA Publishing London, UK, pp. 3–24.

GebreEgziabher, M., Jasechko, S. & Perrone, D. 2022 Widespread and increased drilling of wells into fossil aquifers in the USA. *Nature Comm.* **13**, 2129.

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Geraldi, M. S. & Ghisi, E. 2017 Influence of the length of rainfall time series on rainwater harvesting systems: A case study in Berlin. *Resour. Conser. Recycling* **125**, 169–180.

Ghisi, E. 2010 Parameters influencing the sizing of rainwater tanks for use in houses. *Water Resour. Manage.* **24**, 2381–2403.

Ghisi, E., Bressan, D. L. & Martini, M. 2007 Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil. *Build. Environ.* **42**, 1654–1666.

Giampietro, M. & Funtowicz, S. O. 2020 From elite folk science to the policy legend of the circular economy. *Environ. Sci. Pol.* **109**, 64–72.

Goetz, A., Hussein, H. & Thiel, A. 2023 Polycentric governance and agroecological practices in the MENA region: Insights from Lebanon, Morocco and Tunisia. *Int. J. Water Resour. Dev.* doi:10.1080/07900627.2023.2260902.

Gueldenberg, P. 1998 *Rainwater Management Instead of Rainwater Disposal with the Example of the Residential Area of Breite, Pliensauvorstadt, Stuttgarter-Strasse, Esslingen*. Master Dissertation, Germany (in German).

Gwenzi, W. & Nyamadzawo, G. 2014 Hydrological impacts of urbanization and urban roof water harvesting in water-limited catchments: A review. *Environ. Prog.* **1**, 573–593.

Gwenzi, W., Marumure, J., Makuvara, Z., Simbanegavi, T. T., Njomou-Ngounou, E. L., Nya, E. L., Hoko, Z., Kaeltz, K., Noubactep, C. & Rzymski, P. 2023 The pit latrine paradox in low-income settings: A sanitation technology of choice or a pollution hotspot? *Sci. Tot. Environ.* **879**, 163179.

Han, M. 2007 Revival of rainwater harvesting and management in Asia and the Pacific. In: Jung Kyun Na and Vivian Raksakulthai. Part 1: Vilas Nitivattananon and Shinya Hanaoka. *Sustainable Infrastructure in Asia*. United Nations publication, Bangkok, pp. 109–118.

Han, M. 2013a Progress of multipurpose and proactive rainwater management in Korea. *Environ. Eng. Res.* **18**, 65–69.

Han, M. 2013b Rainwater: Drain? or collect? That is the question. *Environ. Eng. Res.* **18**, 55–56.

Han, M., 2020 The success story of multipurpose rainwater management system at Star City, Korea: Design, climate change adaptation potential and philosophy. In: *International Rainwater Catchment Systems Experiences: Towards Water Security* (Espíndola, J. A. G., Flores, C. A. C., Pacheco-Vega, R. & Montes, M. R. P. eds.). IWA Publishing 2020. doi:10.2166/9781789060584_0229.

Han, M. 2023a *MoMoMo – Management of all Water, for all, by all*. Available from: https://www.thesourcemagazine.org/momomo-management-of-all-water-for-all-by-all/ (accessed 21 September 2023).

Han, M. 2023b *Rain City Initiative to Mitigate Local Climate Crisis Effects*. Available from: https://sdgs.un.org/sites/default/files/2023-03/Written%20Statement%20to%20UN2023%20Water%20Conference%20%28Rain%20City%20Initiative%29%20-%20mooyoung%20Han.pdf (accessed 19 January 2024).

Han, M. Y. & Kim, S. 2007 Local water independency ratio (LWIR) as an index to define the sustainability of major cities in Asia. *Water Sci. Technol. Water Supply* **7**, 1–8.

Han, M. Y. & Mun, J. S. 2011 Operational data of the Star City rainwater harvesting system and its role as a climate change adaptation and a social influence. *Water Sci. Technol.* **28**, 141–150.

Han, M. Y. & Nguyen, D. C. 2018 *Hydrological Design of Multipurpose Micro-Catchment Rainwater Management*. IWA Publishing London, UK.

Hardin, G. 1968 The tragedy of the commons. *Science* **162**, 1243–1248.

Hasse, R. 1989 *Rainwater Reservoirs Above Ground Structures for Roof Catchment*. A Publication of Deutsches Zentrum für Entwicklungstechnologien – GATE in: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Wiesbaden, Germany.

Heijnen, H. 2013 *Enhancing Economic Resilience in North Eastern Brazil by Harnessing Rain*. Rainwater Harvesting Implementation Network (RAIN), Amsterdam.

Henriquez, P. C. 1962 Problems relating to hydrology, water conservation, erosion control, reforestation and agriculture in Curaçao. *New West Indian Guide* **42**, 1–54.

Hering, J. G., Maag, S. & Schnoor, J. L. 2016 A call for synthesis of water research to achieve the sustainable development goals by 2030. *Environ. Sci. Technol.* **50**, 6122–6123.

Howe, K. J., Hand, D. W., Crittenden, J. C., Trussell, R. R. & Tchobanoglous, G. 2012 *Principles of Water Treatment*. John Wiley & Sons, Inc., Hoboken, New Jersey, p. 674.

Huang, Z., Nya, E. L., Rahman, M. A., Mwamila, T. B., Cao, V., Gwenzi, W. & Noubactep, C. 2021a Integrated water resource management: Rethinking the contribution of rainwater harvesting. *Sustainability* **13**, 8338.

Huang, Z., Nya, E. L., Cao, V., Gwenzi, W., Rahman, M. A. & Noubactep, C. 2021b Universal access to safe drinking water: Escaping the traps of non-frugal technologies. *Sustainability* **13**, 9645.

Hughes, M. 2013 The Victorian London sanitation projects and the sanitation of projects. *Int. J. Project Manage.* **31**, 682–691.

Hurayra, M. A. & Rahman, A. 2022 Rainwater harvesting at place of worship: A case study in Australia. *IOP Conf. Ser.: Earth Environ. Sci.* **1022**, 012063.

Islam, M., Kashem, S., Momtaz, Z. & Hasan, M. M. 2023 An application of the participatory approach to develop an integrated water resources management (IWRM) system for the drought-affected region of Bangladesh. *Heliyon* **9**, e14260.

Jayatilaka, C. J., Sakthivadivel, R., Shinogi, Y., Makin, I. W. & Witharana, P. 2003 A simple water balance modelling approach for determining water availability in an irrigation tank cascade system. *J. Hydrol.* **273**, 81–102.

Jung, K., Lee, T., Choi, B. G. & Hong, S. 2015 Rainwater harvesting system for continuous water supply to the regions with high seasonal rainfall variations. *Water Resources Management* **29**, 961–972.

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Kalbar, P. P. & Lokhande, S. 2023 Need to adopt scaled decentralized systems in the water infrastructure to achieve sustainability and build resilience. *Water Policy* **25**, 359–378.

Kapli, F. W. A., Azis, F. A., Suhaimi, H., Shamsuddin, N. & Abas, P. E. 2023 Feasibility studies of rainwater harvesting system for ablution purposes. *Water* **15**, 1686.

Kearns, J., Dickenson, E., Aung, M. T., Joseph, S. M., Summers, S. R. & Knappe, D. 2021 Biochar water treatment for control of organic micropollutants with UVA surrogate monitoring. *Environ. Eng. Sci.* **38**, 298–309.

Kearns, J., Gropper, A., Luis-Muñoz, J. & Yepéz, P. 2023 Adaptable community participatory design to provide water that is Estético, Seguro, y Saludable (pleasant, safe, and healthy) in the Ecuadorian Amazon. *Water Security* **20**, 100150.

Kim, Y., Han, M., Kabubi, J., Sohn, H. G. & Nguyen, D. C. 2016 Community-based rainwater harvesting (CB-RWH) to supply drinking water in developing countries: Lessons learned from case studies in Africa and Asia. *Water Sci. Technol. Water Supply* **16**, 1110–1121.

Kirs, M., Moravcik, P., Gyawali, P., Hamilton, K., Kisand, V., Gurr, I., Shuler, C. & Ahmed, W. 2017 Rainwater harvesting in American Samoa: Current practices and indicative health risks. *Environ. Sci. Pollut. Res.* **24**, 12384–12392.

Kirshanth, L. & Sivakumar, S. S. 2018 Optimization of water resources in the northern province river basins for irrigation schemes used for food production in Sri Lanka. *Int. J. Sci. Eng. Res.* **9**, 569–573.

Krounbi, L., Enders, A., van Es, H., Woolf, D., von Herzen, B. & Lehmann, J. 2019 Biological and thermochemical conversion of human solid waste to soil amendments. *Waste Manage* **89**, 366–378.

Laborde, J.-P. & Morel, M. 1991 Aspects climatologiques liés aux possibilités d'alimentation en eau potable par collecte des eaux pluviales dans le Nord-Cameroun. *Hydrol. Continent.* **6**, 55–66.

Lal, R. 2015a World water resources and achieving water security. *Agron. J.* **107**, 1526–1532.

Lal, R. 2015b Research and development priorities in water security. *Agron. J.* **107**, 1567–1572.

Lane, K. & Kumpel, E. 2023 A critical review of the global use and context of trucked water as a potable water supply. *ACS EST Water* **3**, 1260–1274.

Lashford, C., Rubinato, M., Cai, Y., Hou, J., Abolfathi, S., Coupe, S., Charlesworth, S. & Tait, S. 2019 SuDS & Sponge Cities: A comparative analysis of the implementation of pluvial flood management in the UK and China. *Sustainability* **11**, 213.

Lee, H., Son, T. H., Dzung, D. A., Lee, J., Han, M. & Anh, N. V. 2021 Enhancing the resilience of the rainwater for drinking (RFD) system through systematic monitoring: A case study at the Ly Nhan rural hospital in Vietnam. *J. Water Sanit. Hyg. Dev.* **11**, 1048–1061.

Legates, D. R. 2007 An inconvenient truth: A focus on its portrayal of the hydrologic cycle. *GeoJournal* **70**, 15–19.

Legese, B. & Gum, B. 2020 Flooding in Ethiopia; causes, impact and coping mechanisms. A review. *IJRAR* **7**, 707–717.

Liaw, C.-H. & Chiang, Y.-C. 2014 Framework for assessing the rainwater harvesting potential of residential buildings at a national level as an alternative water resource for domestic water supply in Taiwan. *Water* **6**, 3224–3246.

Loen, S. 2023 Thirsty islands and water inequality: The impact of colonial practices on freshwater challenges in the Dutch Caribbean. *Blue Papers* **2**, 124–131.

Loudyi, D. & Kantoush, S. A. 2020 Flood risk management in the Middle East and North Africa (MENA) region. *Urban Water J.* **17**, 379–380.

MacAllister, D. J., Nedaw, D., Kebede, S., Mkandawire, T., Makuluni, P., Shaba, C., Okullo, J., Owor, M., Carter, R., Chilton, J., Casey, V., Fallas, H. & MacDonald, A. M. 2022 Contribution of physical factors to handpump borehole functionality in Africa. *Sci. Tot. Environ.* **851**, 158343.

Mallory, A., Akrofi, D., Dizon, J., Mohanty, S., Parker, A., Vicario, D. R., Prasad, S., Welivita, I., Brewer, T., Mekala, S., Bundhoo, D., Lynch, K., Mishra, P., Willcock, S. & Hutchings, P. 2020 Evaluating the circular economy for sanitation: Findings from a multi-case approach. *Science of the Total Environment* **744**, 140871.

Marwa, J., Lufingo, M., Noubactep, C. & Machunda, R. 2018 Defeating fluorosis in the East African Rift Valley: Transforming the Kilimanjaro into a rainwater harvesting park. *Sustainability* **10**, 4194.

Morel, M. 1988 *Possibilities of Supplying Drinking Water by Collecting Rainwater in North Cameroon*. PhD Dissertation, Institut national polytechnique de Lorraine, Nancy, France. (In French).

Morote-Seguido, Á. F., Hernández Hernández, M. & Eslamian, S. 2020 Rainwater harvesting in urban areas of developed countries. The state of the art (1980–2017). *Int. J. Hydrol. Sci. Technol.* **10**, 448–470.

Moss, T. 2000 Unearthing water flows, uncovering social relations: Introducing new waste water technologies in Berlin. *J. Urban Technol.* **7**, 63–84.

Moya, B., Parker, A. & Sakrabani, R. 2019a Challenges to the use of fertilisers derived from human excreta: The case of vegetable exports from Kenya to Europe and influence of certification systems. *Food Policy* **85**, 72–78.

Moya, B., Sakrabani, R. & Parker, A. 2019b Realizing the circular economy for sanitation: Assessing enabling conditions and barriers to the commercialization of human excreta derived fertilizer in Haiti and Kenya. *Sustainability* **11**, 3154.

Mun, J. S. & Han, M. Y. 2012 Design and operational parameters of a rooftop rainwater harvesting system: Definition, sensitivity and verification. *J. Environ. Manage.* **93**, 147–153.

Mupangwa, W., Twomlow, S. & Walker, S. 2012 Dead level contours and infiltration pits for risk mitigation in smallholder cropping systems of southern Zimbabwe. *Phys. Chem. Earth A/B/C* **47**, 166–172.

Murphy, H. M., McBean, E. A. & Farahbakhsh, K. 2010 A critical evaluation of two point-of-use water treatment technologies: Can they provide water that meets WHO drinking water guidelines? *J. Water Health* **8**, 611–630.

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by guest

Musaazi, I. G., McLoughlin, S., Murphy, H. M., Rose, J. B., Hofstra, N., Tumwebaze, I. K. & Verbyla, M. E. 2023 A systematic review and meta-analysis of pathogen reduction in onsite sanitation systems. *Water Research X* **18**, 100171.

Musz-Pomorska, A., Widomski, M. K. & Gołebiowska, J. 2020 Financial sustainability of selected rain water harvesting systems for single-family house under conditions of Eastern Poland. *Sustainability* **12**, 4853.

Mwamila, T. B., Han, M. Y., Kim, T. I. & Ndomba, P. M. 2015 Tackling rainwater shortages during dry seasons using a socio-technical operational strategy. *Water Sci. Technol. Water Supply* **15**, 974–980.

Mwamila, T. B., Han, M. Y. & Katambara, Z. 2016 Strategy to overcome barriers of rainwater harvesting, case study Tanzania. *J. Geosci. Environ. Prot.* **4**, 13–23.

Nandi, S. & Gonela, V. 2022 Rainwater harvesting for domestic use: A systematic review and outlook from the utility policy and management perspectives. *Utilities Policy* **77**, 101383.

Naval, R. C. 2016 Socioeconomic impact of small water impounding projects in Quirino Province, Philippines. *J. Geosci. Environ. Protect.* **4**, 101–106.

Ndé-Tchoupé, A. I., Tepong-Tsindé, R., Lufingo, M., Pembe-Ali, Z., Lugodisha, I., Mureth, R. I., Nkinda, M., Marwa, J., Gwenzi, W., Mwamila, T. B., Rahman, M. A., Noubactep, C. & Njau, K. N. 2019 White teeth and healthy skeletons for all: The path to universal fluoride-free drinking water in Tanzania. *Water* **11**, 131.

Nguyen, D. C. & Han, M. Y. 2017 Proposal of simple and reasonable method for design of rainwater harvesting system from limited rainfall data. *Resour. Conserv. Recycl.* **126**, 219–227.

Nguyen, X. C., Nguyen, T. T. H., Bui, X. T., Tran, X. V., Tran, T. C. P., Hoang, N. T. T., La, D. D., Chang, S. W., Ngo, H. H. & Nguyen, D. D. 2021 Status of water use and potential of rainwater harvesting for replacing centralized supply system in remote mountainous areas: A case study. *Environ. Sci. Pollut. Res.* **28**, 63589–63598.

Nichols, G. B. 1885 House drainage in connection with town sewers. *Trans. Sanit. Inst. Great Britain* **6**, 274–277.

Nkiaka, E. 2022 Exploring the socioeconomic determinants of water security in developing regions. *Water Policy* **24**, 608.

Nkwunonwo, U. C. 2016 A review of flooding and flood risk reduction in Nigeria. *Global J. Hum. Soc. Sci. B* **16**, 22–42.

Nya, E. L., Mwamila, T. B., Komguem-Poneabo, L., Njomou-Ngounou, E. L., Fangang-Fanseu, J., Tchoumbe, R. R., Tepong-Tsindé, R., Gwenzi, W. & Noubactep, C. 2023 Integrated water management in mountain communities: The case of feutap in the municipality of Bangangté, Cameroon. *Water* **15**, 1467.

Nya, E. L., Mwamila, T. B., Gwenzi, W. & Noubactep, C. 2024 The potential of farm-scale rainwater harvesting for irrigation in regions with saline groundwater. In: *Accepted for the International Conference Maji 2024 in Dar es Salaam (Tanzania)*.

Ogisma, L. 2022 *Ensuring Safe Drinking Water for the Northern Corridor of Haiti Through Expanded Testing Services*. PhD Dissertation, Auburn University, USA.

Ostrom, E. 1996 Crossing the great divide: Co-production, synergy and development. *World Dev.* **24**, 1073–1087.

Ostrom, E. 2000 Collective action and the evolution of social norms. *J. Econ. Perspect.* **14**, 137–158.

Pandey, D. N., Gupta, A. N. & Anderson, D. M. 2003 Rainwater harvesting as an adaptation to climate change. *Curr. Sci.* **85**, 46–59.

Parker, Y. P., Parchment, K. F. & Gordon-Strachan, G. M. 2023 The burden of water insecurity: A review of the challenges to water resource management and connected health risks associated with water stress in small island developing states. *J. Water Clim. Chang.* doi:10.2166/wcc.2023.239.

Parry, K. 1885 Domestic drainage in Dublin. *Ireland Trans. Sanit. Inst. Great Britain* **6**, 277–281.

Pembe-Ali, Z., Mwamila, T. B., Lufingo, M., Gwenzi, W., Marwa, J., Rwiza, M. J., Lugodisha, I., Qi, Q. & Noubactep, C. 2021 Application of the Kilimanjaro concept in reversing seawater intrusion and securing water supply in Zanzibar, Tanzania. *Water* **13**, 2085.

Ponte, S., Noe, C. & Mwamfupe, A. 2021 Private and public authority interactions and the functional quality of sustainability governance: Lessons from conservation and development initiatives in Tanzania. *Regul. Gov.* **15**, 1270–1285.

Prakongsri, P. & Santiboon, T. 2020 Effective water resources management for communities in the Chi River Basin in Thailand. *Environ. Claims J.* **32**, 323–348.

Preneta, N., Kramer, S., Magloire, B. & Noel, J. M. 2013 Thermophilic co-composting of human wastes in Haiti. *J. Water Sanit. Hyg. Dev.* **3**, 649–654.

Puppala, H., Ahuja, J., Tamvada, J. P. & Peddinti, P. R. T. 2023 New technology adoption in rural areas of emerging economies: The case of rainwater harvesting systems in India. *Technol. Forecast. Soc. Change* **196**, 122832.

Qi, Q., Marwa, J., Mwamila, T. B., Gwenzi, W. & Noubactep, C. 2019 Making rainwater harvesting a key solution for water supply: The universality of the Kilimanjaro concept. *Sustainability* **11**, 5606.

Ramabrahmam, K., Keesara, V. R., Srinivasan, R., Pratap, D. & Sridhar, V. 2023 Climate change impact on water resources of tank cascade systems in the Godavari Sub-Basin, India. *Water Resour. Manage.* **37**, 2853–2873.

Reijtenbagh, R. 2010 *Towards a Design for an Improved Drinking Water Supply System on Bonaire, St Eustatius and Saba. Master Dissertation*, Delft University of Technology, Delft, The Netherlands.

Richards, L. A., Parashar, N., Kumari, R., Kumar, A., Mondal, D. & Polya, D. A. 2022 Household and community systems for groundwater remediation in Bihar, India: Arsenic and inorganic contaminant removal, controls and implications for remediation selection. *Sci. Total. Environ.* **830**, 154580.

Ross, T. T., Alim, M. A. & Rahman, A. 2022 Community-scale rural drinking water supply systems based on harvested rainwater: A case study of Australia and Vietnam. *Water* **14**, 1763.

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Rygaard, M., Binning, P. J. & Albrechtsen, H.-J. 2011 Increasing urban water self-sufficiency: New era, new challenges. *J. Environ. Manage.* **92**, 185–194.

Sanches Fernandes, L. F., Terêncio, D. P. S. & Pacheco, F. A. L. 2015 Rainwater harvesting systems for low demanding applications. *Sci. Tot. Environ.* **529**, 91–100.

Scalley, T. H. 2012 Freshwater resources in the insular Caribbean: An environmental perspective. *Caribbean Studies* **40**, 63–93. ,.

Schumacher, E. F. 1973 *Small is Beautiful: Economics as if People Mattered*. Harper & Row, New York, p. 324.

Semaan, M., Day, S. D., Garvin, M., Ramakrishnan, N. & Pearce, A. 2020 Optimal sizing of rainwater harvesting systems for domestic water usages: A systematic literature review. *Resour. Conserv. Recycl. X* **6**, 100033.

Serrao-Neumann, S., Renouf, M., Kenway, S. J. & Low-Choy, D. 2017 Connecting land-use and water planning: Prospects for an urban water metabolism approach. *Cities* **60**, 13–27.

Shahid, M., Cong, Z. & Zhang, D. 2018 Understanding the impacts of climate change and human activities on streamflow: A case study of the Soan River basin, Pakistan. *Theor. Appl. Climatol.* **134**, 205–219.

Shahid, M., Rahman, K. U., Haider, S., Gabriel, H. F., Khan, A. J., Pham, Q. B., Pande, C. B., Linh, N. T. T. & Anh, D. A. 2021 Quantitative assessment of regional land use and climate change impact on runoff across Gilgit watershed. *Environ. Earth Sci.* **80**, 743.

Shannon, K. & Manawadu, S. 2007 Indigenous landscape urbanism: Sri Lanka's reservoir and tank system. *J. Landscape Arch.* **2**, 6–17.

Sharma, A., Burn, S., Gardner, T. & Gregory, A. 2010 Role of decentralised systems in the transition of urban water systems. *Water Supply* **10**, 577–583.

Sikder, M., Mirindi, P., String, G. & Lantagne, D. 2020 Delivering drinking water by truck in humanitarian contexts: Results from mixed-methods evaluations in the Democratic Republic of the Congo and Bangladesh. *Environ. Sci. Technol.* **54**, 5041–5050.

Silayo, V. M. & Pikirayi, I. 2023 Community-based approaches in the construction and management of water infrastructures among the Chagga, Kilimanjaro, Tanzania. *Land* **12**, 570.

Słyś, D. & Stec, A. 2020 Centralized or decentralized rainwater harvesting systems: A case study. *Resources* **9**, 5.

Smakhtin, V. U. & Piyankarage, S. C. 2003 Simulating hydrologic reference condition of coastal lagoons affected by irrigation flows in southern Sri Lanka. *Wetlands* **23**, 827–834.

Snir, O., Friedler, E. & Ostfeld, A. 2022 Optimizing the control of decentralized rainwater harvesting systems for reducing urban drainage flows. *Water* **14**, 571.

Soh, Q. Y., O'Dwyer, E., Acha, S. & Shah, N. 2023 Robust optimisation of combined rainwater harvesting and flood mitigation systems. *Water Res.* **245**, 120532.

Sousa, V., Silva, C. M. & Meireles, I. C. 2018 Technical-financial evaluation of rainwater harvesting systems in commercial buildings – Case studies from Sonae Sierra in Portugal and Brazil. *Environ. Sci. Pollut. Res.* **25**, 19283–19297.

Taghavi-Jeloudar, M., Han, M., Davoudi, M. & Kim, M. 2013 Review of ancient wisdom of Qanat, and suggestions for future water management. *Environ. Eng. Res.* **18**, 57–63.

Tepong-Tsindé, R. 2021 Designing and piloting a household filter for the peri-urban population of Douala (Cameroon). *Freiberg Online Geosci.* **61**, 1–80.

Tilmans, S., Russel, K., Sklar, R., Page, L., Kramer, S. & Davis, J. 2015 Container-based sanitation: assessing costs and effectiveness of excreta management in Cap Haitien. *Haiti. Environ. Urban.* **27**, 89–104.

Umapathi, S., Pezzaniti, D., Beecham, S., Whaley, D. & Sharma, A. 2019 Sizing of domestic rainwater harvesting systems using economic performance indicators to support water supply systems. *Water* **11**, 783.

Umar, N. & Gray, A. 2023 Flooding in Nigeria: A review of its occurrence and impacts and approaches to modelling flood data. *Int. J. Environ. Stud.* **80**, 540–561.

Unsal, B., Yagbasan, O. & Yazicigil, H. 2014 Assessing the impacts of climate change on sustainable management of coastal aquifers. *Environ. Earth Sci.* **72**, 2183–2193.

Valdez, M. C., Adler, I., Barrett, M., Ochoa, R. & Pérez, A. 2016 The water-energy-carbon nexus: Optimising rainwater harvesting in Mexico City. *Environ. Process.* **3**, 307–323.

Vallés-Casas, M., March, H. & Saurí, D. 2016 Decentralized and user-led approaches to rainwater harvesting and greywater recycling: The case of Sant Cugat del Vallès, Barcelona, Spain. *Built Environ.* **42**, 243–257.

van Buurt, G. 2018 *Water Conservation in Curaçao; Using Traditional Earthen Dams*. Available from: https://www.dcbd.nl/sites/default/files/documents/vanBuurt%282022%29_waterConservationCuracaoTraditionalDams.pdf (Accessed: 15 January 2024).

van der Heijden, S., Cassivi, A., Mayer, A. & Sandholz, S. 2022 Water supply emergency preparedness and response in health care facilities: A systematic review on international evidence. *Front. Public Health* **10**, 1035212.

van Ginkel, K. C. H., Hoekstra, A. Y., Buurman, J. & Hogeboom, R. J. 2018 Urban water security dashboard: Systems approach to characterizing the water security of cities. *J. Water Resour. Plann. Manage.* **144**, 04018075.

van Meter, K. J., Basu, N. B., Tate, E. & Wyckoff, J. 2014 Monsoon harvests: The living legacies of rainwater harvesting systems in South India. *Environ. Sci. Technol.* **48**, 4217–4225.

Vavrus, F. K. 2003 'A shadow of the real thing': Furrow societies, water user associations, and democratic practices in the Kilimanjaro Region of Tanzania. *J. Afr. Am. Hist.* **88**, 393–412.

Vialle, C., Busset, G., Tanfin, L., Montrejaud-Vignoles, M., Huau, M.-C. & Sablayrolles, C. 2015 Environmental analysis of a domestic rainwater harvesting system: A case study in France. *Resour. Conserv. Recycl.* **102**, 178–184.

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Vitale, C. & Meijerink, S. 2023 Flood risk policies in Italy: A longitudinal institutional analysis of continuity and change. *Int. J. Water Resour. Dev.* **39**, 211–235.

Wahab, B. & Ojolowo, S. K. 2013 Rainwater harvesting: Harnessing traditional approach to reduce flash floods in Ibadan Metropolis. *lbadan Plan. J.* **2**, 39–60.

Waseem, M., Ghazi, S. M. U., Ahmed, N., Ayaan, M. & Leta, K. M. 2023 Rainwater harvesting as sustainable solution to cope with drinking water scarcity and urban flooding: A case study of public institutions in Lahore, Pakistan. *CivilEng* **4**, 638–656.

Whittington, D., Jeuland, M., Barker, K. & Yuen, Y. 2012 Setting priorities, targeting subsidies among water, sanitation, and preventive health interventions in developing countries. *World Dev.* **40**, 1546–1568.

Wong, T. H. & Brown, R. R. 2009 The water sensitive city: Principles for practice. *Water Sci. Technol.* **60**, 673–682.

Woodhouse, P., Jan Veldwisch, G., Venot, J.-P., Brockington, D., Komakech, H. & Manjichi, Â. 2017 African farmer-led irrigation development: Re-framing agricultural policy and investment? *J. Peasant Stud.* **44**, 213–233.

Xiao, M., Hu, R., Gwenzi, W., Tao, R., Cui, X., Yang, H. & Noubactep, C. 2024 Designing sustainable Fe^0–based water filters: The crucial role of material selection. *Environ. Chem. Lett.* (ECLE-D-23-01068, in revision).

Younos, T. 2011 Paradigm shift: Holistic approach for water management in urban environments. *Front. Earth Sci.* **5**, 421–427.

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