Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2015.1021097

57 (2016) 95–104
January

Taylor & Francis
Taylor & Francis Group

State of the art of rainwater harvesting systems towards promoting green built environments: a review

Ali GhaffarianHoseini[a], John Tookey[a], Amirhosein GhaffarianHoseini[b,*], Safiah Muhammad Yusoff[b], Norhaslina Binti Hassan[b]

[a]*Faculty of Design and Creative Technologies, School of Engineering, AUT University, Auckland, New Zealand*
[b]*Faculty of Arts and Social Sciences, Department of Geography, University of Malaya (UM), Kuala Lumpur, Malaysia, Tel. +60 173178104; email: dr.amirhosein@um.edu.my (A. GhaffarianHoseini)*

Received 5 October 2014; Accepted 4 February 2015

ABSTRACT

Water scarcity, imperfect consumption patterns, rapid global population increase, surpassing consumption ratio, and several further factors overstress the urging necessity to systematically access and utilize supplementary and most importantly renewable water supply resources. Moreover, application of suitably designed and well-maintained rainwater harvesting systems within the context of the built environment while generalizing the focus on diverse building typologies is promoted as a promising resolution to these systemic issues. Despite the numerous positive benefits of utilizing rainwater harvesting as a means of supporting sustainable development and green built environments, there exists a gap in properly integrating these design features to deliver congruent sustainable outcomes. Accurate design and configuration, simulation, localization, and imposing proper maintenance schemes are expected to be followed in order to accomplish the ultimate goal of executing rainwater harvesting systems. Besides the inevitable noteworthy role of governments in educating, providing prospects and supporting these decentralized water supply and consumption systems is encouraged. Ultimately, this paper provides an overview on the contemporary rainwater harvesting systems, the respective implications and systematic configurations, quality assessments, the potential of rightfully merging them with green roofs and green built environment criteria, and eventually manipulated government regulation to provide insights for overcoming the aforementioned intensifying rainwater-related concerns.

Keywords: Rainwater harvesting systems; Green built environment; Renewable water resources; Water scarcity; Government policies

1. Introduction

For a sustainable urban future, water supply has become a critical issue globally. Cities are rapidly growing and their infrastructure evolving to fulfill the rising demands of inhabitants. Numerous studies have accordingly drawn attention to the circumstances of creating greener and smarter urban areas in order to respond to the current social demands and

*Corresponding author.

Presented at the International Conference on Business, Economics, Energy and Environmental Sciences (ICBEEES) 19–21 September 2014, Kuala Lumpur, Malaysia

environmental issues. Accordingly, global water resources (Fig. 1) have become an international matter of significant concern according to the rapid growth (Fig. 2) of global population [1].

UNEP expressed that only less than 1% (2.5% including frozen and snow-covered) of all existing freshwater resources are consumable for humans. However, even this small proportion of currently available freshwater resources is being eroded through incremental pollution (Fig. 3).

Nevertheless, the water consumption increase rate during the previous century has been twice the rate of global population growth [4]. Besides, promotion of sustainable urban development urges to consider reduction of desalinated water supply dependence as well as decrease of energy-intensive water treatment approaches [5]. Consequently, as absolute water demand grows, the need to identify and exploit alternative water resources becomes more severe [6].

1.1. Rainwater harvesting systems and implications

Water scarcity, as the result of water demand surpassing accessible water resources, can occur virtually anywhere. Scarcity is usually associated with arid climates and areas with low water availability. However, it can also potentially occur in areas with high rainfall due to either population density or excessive residential-agricultural-industrial water consumptions. This then highlights the need for ongoing access to renewable water resources [7]. A further factor compounding the problem comes from inefficient water transmission, treatment, and disposal system demanding large amounts of resource and energy resulting in undesired additional costs and environmental degradation [6].

It is evident that the observed severe droughts, increased water demands, and the impacts of stormwater run-offs highlighted have attracted the attention of academicians and practitioners to apply rainwater harvesting systems. Rainwater captured as run-off

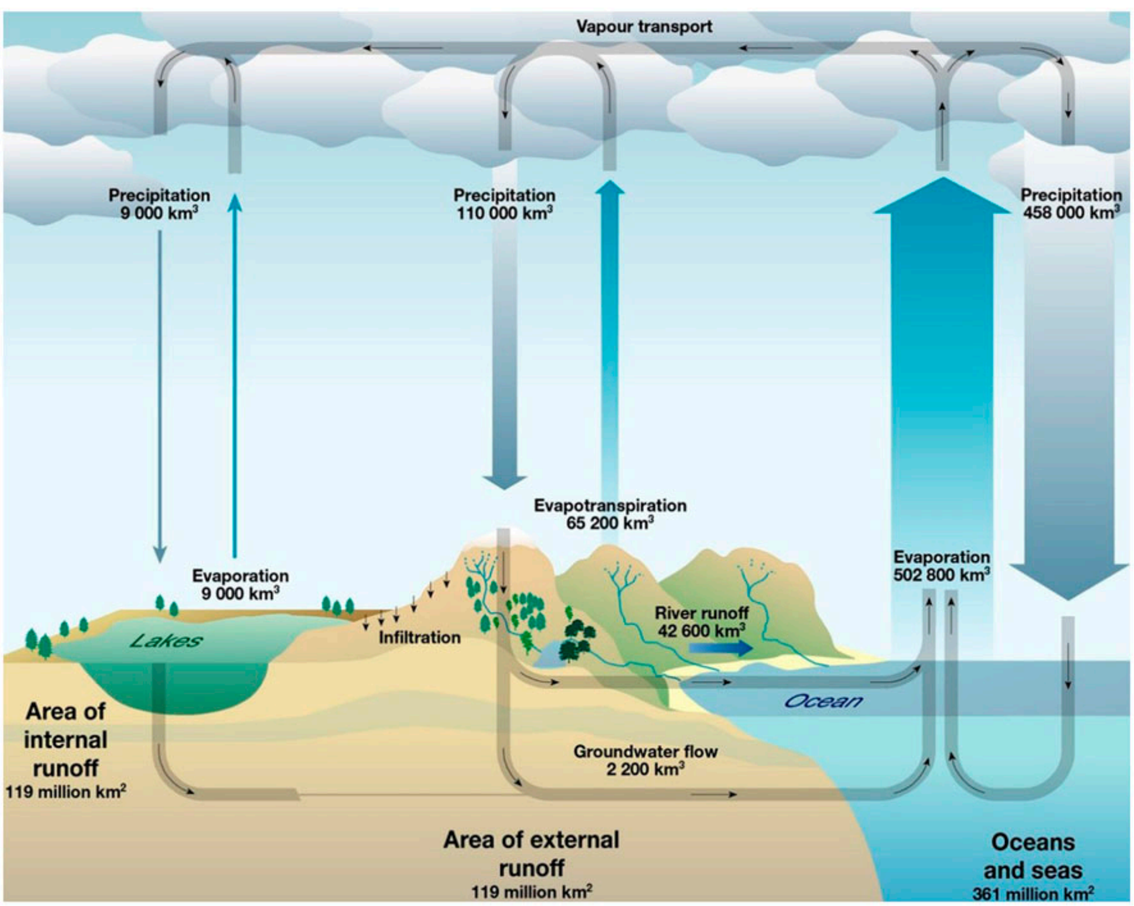

Fig. 1. Global water cycle—source [2].

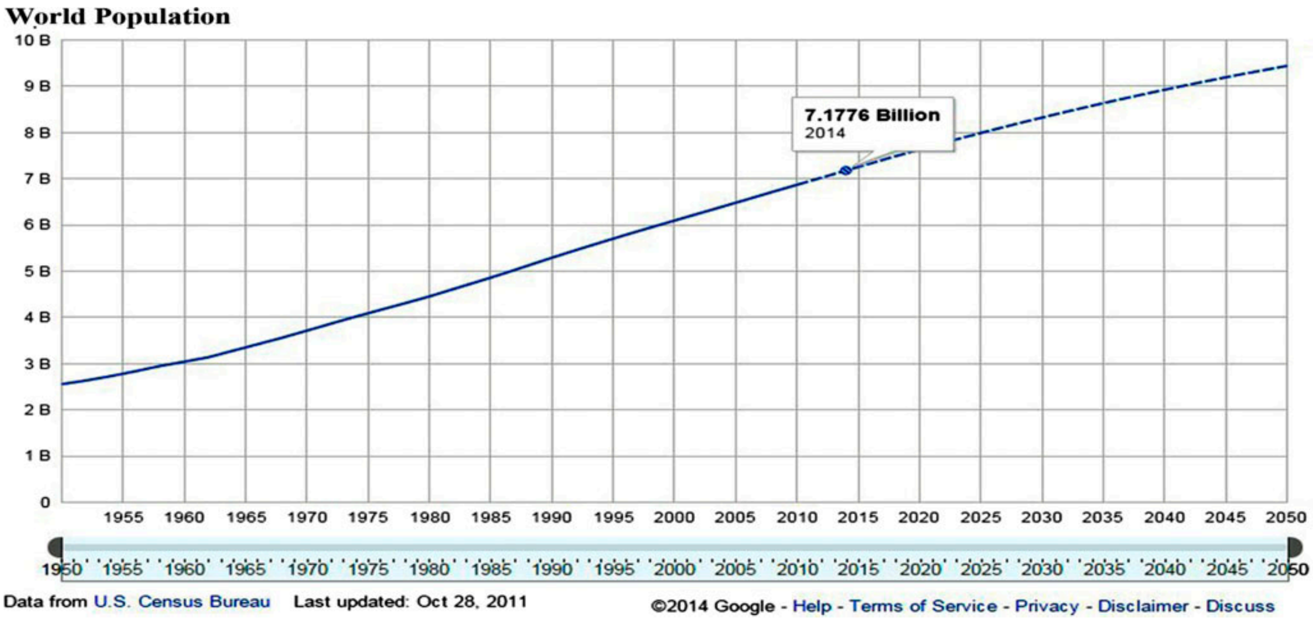

Fig. 2. World population growth—source [3].

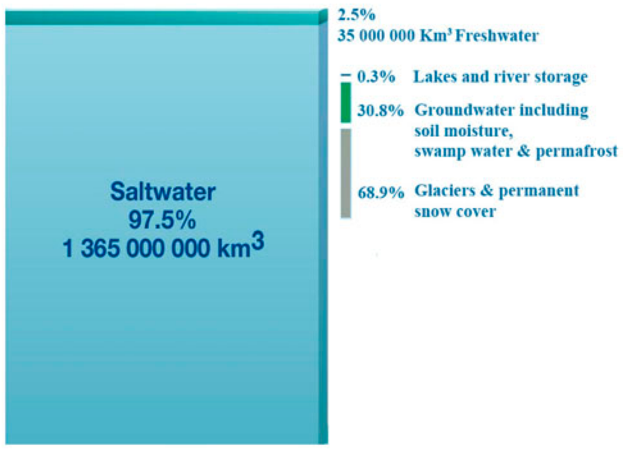

Fig. 3. World saline and fresh water supply—source [2].

from built assets has thus been identified as providing an invaluable supplement to existing water supply resources.

There are some obvious substantial sustainability benefits that can accrue from harvesting rainwater from built assets, rather than having to manage and reticulate that water away. Thus, it is apparent that there is a pressing need to implement observational studies on the performance of alternative water supply technologies aligned with sustainability objectives [8]. Rainwater harvesting is proven to be beneficial while utilized in urban areas; however, as there exist various rural areas around the world with either no or limited access to potable water, the role of applying rainwater harvesting systems in these areas is equally vital for future sustainability of populations [5]. Despite the potential existence of obstacles along the way, application of rainwater harvesting systems in humid and well-developed regions is expected to be effective [9]. While rainwater harvesting is considered to have moderate effects in urban areas with average rainfall, it is proven to be inefficient in areas with arid climates [10].

Rainwater harvesting consists of technology to simply collect and store rainwater from rooftops, land surfaces, or rock catchments. In its elementary form, rainwater harvesting utilizes simple storage tanks and cisterns to contain run-off from infrastructure for future use within that infrastructure or closely situated facilities. There are more complicated approaches similarly used, including underground check dams to achieve similar outcomes [11]. Generally, rainwater harvesting systems include a waterproof catchment surface to initially collect the rainwater, a delivery system to transfer the collected rainwater to storage tanks, and eventually the storage tank. It is recommended to use either plastic or metal equipment within the systems based on their high durability [9]. Fig. 4 indicates the configuration of a typical rainwater harvesting system.

The harvested rainwater is an ideal, clean, and renewable source of water supply for consumption during residential and non-residential practices [5]. Fig. 5 indicates the total global renewable water resources.

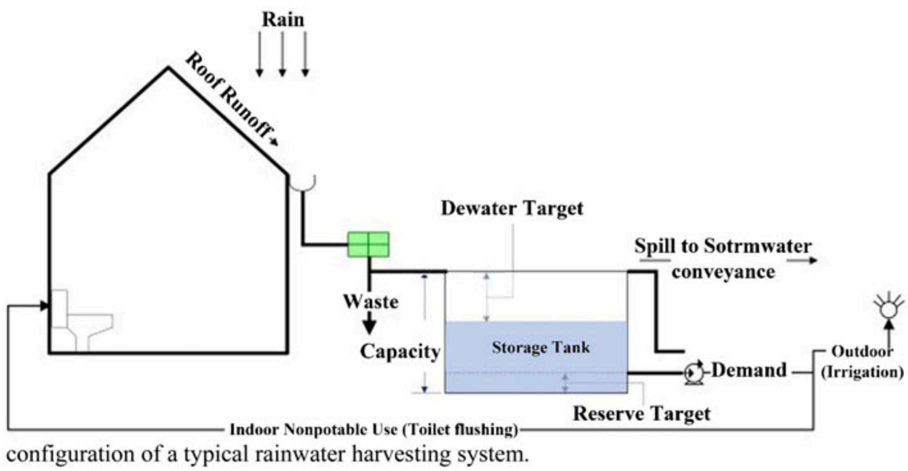

Fig. 4. A typical rainwater harvesting system—source [12].

Rainwater harvesting is not only about collecting and saving water as an auxiliary supply for the growing demand. There are further implications as part of wider water management strategy, including individuals rationalizing and managing water collection, storage, and consumptions [11]. In addition to its basic functionality, rainwater harvesting in urban areas can also prevent urban stream degradation and urban flooding through providing an attenuating "buffer" for excess water in the event of extreme precipitation [5].

Rainwater harvesting assists with facilitating potable and non-potable water resources. Even in instances that the storage tank water is expected to be used for non-potable purposes, such as toilet flushing, laundry, outdoor landscape use, and irrigation, these practices account for about 80% of the overall typical household water consumption [9].

1.2. Rainwater harvesting—design and configurations

Suitable design and simulation to inspect the efficiency of the proposed rainwater harvesting systems enhances its benefits [13]. The task is complex. Identifying the performance metrics and configuration

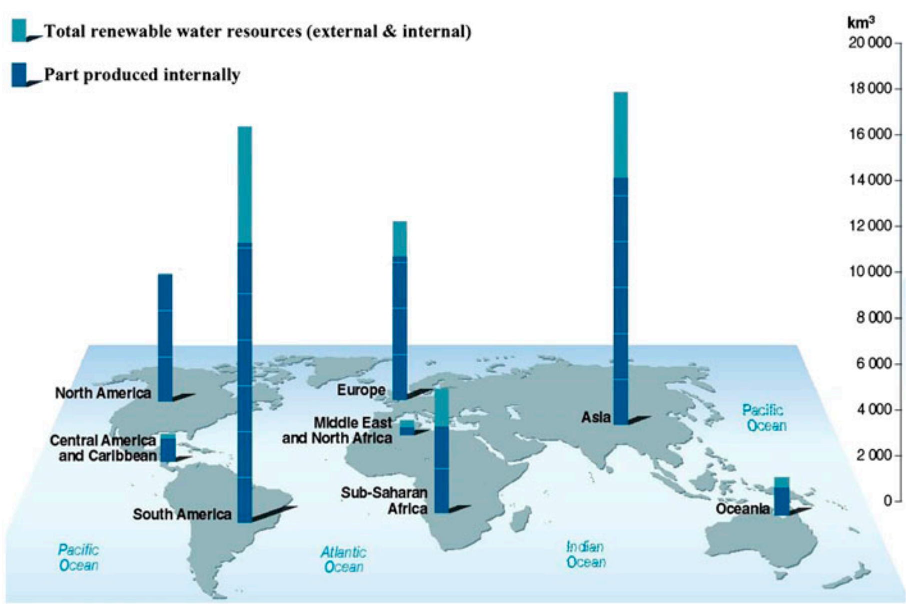

Fig. 5. Total global renewable water resources—source [2].

of a rainwater harvesting system design regularly incorporates consideration of incompatible objectives. These include the requirement for it to provide a reliable water supply, minimization of run-off volume and moderating the system implementation costs. Correspondingly, it is highly advisable to simulate and assess the performance of a rainwater harvesting system over an extensive duration of time. In effect, a life cycle approach has to be considered in the establishment of the system, and accordingly interpret its capability to meet water quality, supply, and eventually the economic objectives. Table 1 indicates the typical sub-systems of a rainwater harvesting setup.

Design and configuration of an optimal rainwater harvesting system is a complex task. There are multiple optimal—and near optimal—solutions based on diverse compositions of impermeable surface measurements, capacity of storage tanks, rainwater stipulation, and the local demand for water. This complicates selection of the most appropriate combination of parameters. Consequently, researchers have introduced the rainwater accumulation potential as an alternative independent variable requiring measurement [8].

Application of specifically designed rainwater harvesting systems tends to be beneficial used in conjunction with certain building typologies and consumption patterns. Researchers have emphasized on the importance of integrating such systems with facility designs according to their capability of drastically reducing the municipal water consumption. Various different uses of the harvested water need to be considered. In the event that it is intended for human consumption, then there is a need to treat the water. This can be done through different natural or artificial filtration systems [15,16]. A more commonly used option is the "halfway house" of using the water for purposes other than drinking. For example, watering gardens, flushing toilets, etc. All these uses have a beneficial impact since the water is obtained at minimal cost and with little strain on the infrastructure from pumping the rainwater throughout the system. However, appropriate observation and maintenance is anticipated to be applied in order to ensure the accomplishment of aforementioned systems [9].

As the main feature of designing an appropriate rainwater harvesting system and in order to capitalize on rainwater storage, design, selection, and capacity of the corresponding water storage tanks plays an important role.

Respectively, it is essential to rigorously study the regional amount of rainfall and the corresponding area of the roof as two key elements regarding this matter [10].

1.3. Rainwater harvesting—water storage tanks

Prior research has demonstrated that larger rainwater tank sizes with higher storage capacity can maximize the water saving in multi-unit buildings. Paradoxically, this more intensive land use could potentially limit space for rainwater storage tanks in a multi-unit building. Consequently, consideration needs to be made of providing adequate rainwater storage tank space during the building design stages. Application of higher capacity storage tank is widely regarded as the main criteria towards efficient rainwater harvesting. But this is not the ultimate solution. Design creativity and innovative thinking also needs to be woven into the design process. For

Table 1
The typical sub-systems of a rainwater harvesting set-up—source [14]

Sub-system	Function	Main parts and components	Design criteria
Collection	Collect and convey rainwater	Catchment area, and conveyance pipes (gutters and downpipes)	Optimization of the quality and quantity of raw rainwater yields
Treatment	Improve rainwater quality	Treatment equipment or apparatus	Quality control to comply with guidelines for non-potable and seldom potable water use
Storage	Reserve rainwater for future use	Storage tank	Balance between rainwater yield and consumption
Distribution	Supply rainwater from storage tank to end use points	Distribution apparatus (e.g. pipes, connections, pumps, header tanks)	Required supply pressure and flow rate, installation and operation costs, and energy consumption
Town water	Supplement rainwater supply when	Rainwater back-up apparatus (e.g. valves and controllers)	Ensure continuous reliable supply of water to
Back-up	Rainwater cannot meet demand	To enable switching to town water supply	Consumption points when rainwater is not available

example, allocation of water storage tanks in building foundations, utilization of the tanks as aesthetic landscape elements, and alternatively the use of a connected sequence of small tanks as opposed to a single oversized tank have also been solutions towards this matter [17]. However, a larger tank imposes higher costs of purchasing and installation. It is also expressed that the main preventing factor for users to implement these systems is the initial capital investment for setup and installations.

Global location is a key factor in determining the proper configuration of an effective rainwater harvesting system. Rainfall patterns vary by region, latitude, and altitude of an urban area. Thus, rainwater harvesting tank size configuration and measurements vary by city and its regional characteristics. Users in different locations of a certain city would require access to customized rainwater harvesting tanks with alternative sizes in order to maximize their return on investment. Consequently, it is advisable for researchers to consider multiple annual rainfall data patterns in multiple regionally diverse rainfall stations to assist the end users with selecting the optimum tank size [18].

In humid climates, tank sizes and capacities can be minimized and rationalized to mainly focus on collection and storage of rainwater from rooftops. High levels of water availability means that storing water in oversized tanks for prolonged periods is redundant [19]. Thus in high humidity conditions, there is an expectation of using water resources in "rapid turnover" applications—for example, grey water toilet flushing. According to the available versatile techniques and methodological approaches to determine rainwater harvesting configurations and tank sizes, it has been established that simplified and intermediate methods are inefficient while considering commercial and industrial complexes. This is primarily as a result of their irregular water stipulation, yield uncertainty, and the predominantly complex systems needed, which include large-sized and costly storage tanks [9]. Eventually, access to a widespread decision support mechanism is required to facilitate optimal design of collection technique and storage tank size in every geographical location [20].

1.4. Rainwater harvesting systems—quality assessment and critical factors

The quality of collected rainwater will not necessarily be always up to the accepted potable standards from any catchment without treatment. This is inevitable as a result of the possibility of urban environmental pollution, as well as other chemical and microbiological contaminations. Various factors impact on this probability, including such issues as the geographical location, previous dry days, season of the year, human/animal activities, temperature inversions, as well as the adjacency of diverse potentially pollutant sources affect the quality of rainwater harvesting systems [21]. It is articulated that the harvested rainwater quality also depends on environmental conditions, such as the atmospheric pollution and regional climatic conditions as well as the roof materials and typologies [21]. Furthermore, quality of the harvested rainwater is fundamentally dependent on the impermeable substrate being used to capture the rainfall. As a result, the importance of analyzing the rainwater quality according to roof material type is essential. Similarly, there is a critical requirement to monitor microbial pathogens and pesticides in the harvested rainwater according to roof materials as well as considering the first-flush effect [22].

Assessment of the harvested rainwater quality specifically for domestic consumption based on roof water run-off collections is primarily vital due to the potential existence of microbial pathogens, nutrient pollution (total phosphorus and nitrate nitrogen), heavy metal contamination (i.e. lead), and pesticides [21,23–25].

1.5. Rainwater harvesting—rooftops

As mainly urban buildings are covered by roofs, the potential of utilizing urban areas for rainwater harvesting is very clear [10]. Rainwater harvesting from roofs has been widely used as an easily workable mechanism for harvesting rainwater, since their run-off is less polluted that off other impermeable surfaces—such as tarmac roads, parking lots, etc. Furthermore, urban roofs do not have temporary surface water subject to pathogen growth or have a propensity to the salinization seen from underground water supplies [5,13].

Collected water from roofs of versatile buildings has been utilized for both potable and non-potable purposes. Generally, they are used for irrigation purposes in order to be considered as an additional source of water supply per se. In reality, it is possible for rainwater harvesting systems to help decrease total potable water consumption from centralized resources [6] if the technology was widely implemented in building design.

Although metal roofs are often recommended for rainwater harvesting systems implementations, utilization of alternatives such as cool roofs and concrete tile roofs are also options. Typical green roofs are usually not suggested for roof-based rainwater harvesting systems. This is due to the existence of dissolved organic carbon concentrations in green roof water run-offs [13,22,26].

Appropriately constructed and maintained rooftop rainwater catchments usually result in collection of less-contaminated and potentially potable water. Ideally, such roofs do not require further treatments compared to conventional and insecure rooftops. However, elevated possibility of contamination for ground and surface rainwater catchments highlights them as typically not suitable for human consumption purposes unless appropriately treated [27].

2. Incorporating rainwater harvesting, sustainable implementations, and green built environments

Recent research has focused on improving the sustainability performance of green buildings [28]. In order to make significant inroads into climate change, it is necessary to improve a range of sustainability practices. These will inevitably incorporate optimized (i.e. sustainable), water consumption and management practices. Furthermore, examining and assessing innovative water conservations technologies according to social, environmental, and economic features is highlighted [4].

Rainwater harvesting is an essential component in achieving future sustainable urban development through the provision of supplementary water resources for growing urban populations. Not only does rainwater harvesting optimize consumption and management of water resources, but it also promotes sustainable development with specific focus on the context of the built environment [1].

In conjunction with residential infrastructures, industrial and commercial buildings also contribute towards the ecological footprint of the urban environment. Therefore, sustainable considerations focusing on water resource management should be applied throughout these infrastructures. Respectively, commercial buildings are advised to apply decentralized water supply management systems. However, without appropriate observational studies to evaluate their corresponding performance, adaptability of the ultimate sustainability objectives is not ensured [29]. Decentralized rainwater harvesting technologies are considered as sustainable, eco-friendly, and green water supplies [7]. Correspondingly, use of decentralized rainwater harvesting systems directly helps overcoming water scarcity, promoting pollution reductions and achieving economic success [30,7].

Despite the clear preference of the energy sector on renewable resources over the fossil technologies [28,31], the water supply sector appears to lack clear preferences on delivery of sustainable water resources over the conventional practices. Correspondingly, despite the contribution of decentralized rainwater harvesting systems towards sustainability, centralized infrastructure is still widely given priority compared to decentralized options.

3. Rainwater harvesting systems—green roofs and run-off water

Rainwater harvesting depends on annual rainfall patterns, water-retaining capacity, and run-off coefficient of roofs. An extensive green roof is capable of retaining up to 55% of the yearly rainfall consequential towards capacities to control the urban stormwater run-off while diminishing urban flooding likelihood. Urban and peri-urban stormwater run-off is regarded as a substantial contributor to pollution of downstream marine ecosystems, as well as waterway and damage to marine habitat [32]. Accordingly, operationalizing green roofs in urban areas is regarded as beneficial in reducing the urban stormwater run-off, and promoting sustainable and eco-friendly environments [33].

Optimization of green roofs is dependent on humidity, water ingress into building envelope, rainfall intensity, concentration, and transpiration and evaporation potentials and soil hydraulic properties. Preceding research simulations have shown a high degree of effectiveness for green roofs in dealing normal precipitation. Experiencing more substantial rainfall, green roofs are able to reduce the run-off flow intensity while concurrently lengthening the water run-off period—thus decreasing surge and preventing urban flooding [34].

Green roofs assist in stabilizing the harvested rainwater pH to almost neutral; however, they are seen to increase the concentration of ions in the run-off water. Numerous cases showed discharge of heavy metals, such as Fe, Al, and Cu in green roof run-off water. Furthermore, green roofs filter out nutrients from the run-off water, such as nitrates and phosphates. Therefore, despite the various positive influences of implementing green roofs in urban environment [28,35,36], their use is not ideal for integration with roof run-off-based typical rainwater harvesting systems. Therefore, it is recommended to establish research into development guidelines for green roof design and implementation systems [23,32].

4. Rainwater harvesting systems and government regulations and policies

Despite the positive potential for rainwater harvesting to augment sustainable urban development, it has often been considered a risk, rather than an opportunity. However, modern societies have been promoting application of rainwater harvesting systems through providing incentives for individuals practicing it [37]. Similarly, in spite of various research indicating positive results regarding rainwater harvesting, countries and jurisdictions are reluctant to mandate its use into building codes and practice. In part, this is as a lack of awareness about its effectiveness, but also because the specifications needed for optimized performance are not universally available [8].

Due to the imperfect knowledge of the life cycle expenditure of the rainwater harvesting system, it is difficult for many potential users to identify the possible benefits of these systems. Researchers have recommended that governments compensate the willing households to incentivize the use of these technologies, and thus promote sustainable water supply and management systems [38]. Application of rainwater harvesting as a decentralized water supply system requires active engagement of individuals, hence limiting the control of authorities over the central urban water supply flow [7]. The relatively low price of water supply in many countries is due to the respective government subsidies; thus, dynamic involvement of citizens in rainwater harvesting practices can fundamentally help reduce government subsidies if appropriately utilized [11].

Table 2 indicates a systematic comparison between conventional and sustainable water infrastructures [39]. It highlights significant differences in the fundamental philosophies of conventional and sustainable water infrastructures. It also gives an idea as to how government policies and regulation may be used to encourage sustainable development.

It has been established that long return periods to repay initial capital investment in dwellings implementing rainwater harvesting systems decreases the feasibility of their broad adoption. This is the reality of dealing with private householders. They may feel good about how sustainably they are living—their "green credentials". However, unless there is a rapid return on investment, there is no economic imperative to make a change from "normal practice." Such private householders need to be incentivized to change through governmental support in the form of grants or subsidies (the so-called "carrot" approach). Alternatively, private householders need to be driven to adopt these technologies through a current (or proposed future) change in legislation. This latter approach can lead to older houses being non-compliant with current codes and therefore less attractive for sale. In the worst case, it can leave private householders with substantial *ex post facto* liabilities for upgrade. The feeling of "punishment" tied to such a governmentally led regulation change means that it is sometimes referred to as the "legislative stick". Most governments that seek to introduce rainwater harvesting for the reasons cited end up resorting to some sort of hybrid carrot/stick policy to enforce change over a prescribed period.

In contrast, the economics of larger projects such as public buildings are substantially more feasible according to a relatively shorter payback time in comparison with the building's anticipated life cycle [6]. The success of rainwater harvesting as a policy is built upon a combination of clear economics for public buildings, allied to an encouragement/compulsion strategy for non-governmental actors. This multi-stakeholder approach increases levels of engagement with the technologies as well as the probability of overall success [37].

Straightforward installation and maintenance of rainwater harvesting systems in urban areas is compared to the costly and complex operation and upholding of centralized municipal water supply

Table 2
Water infrastructures (conventional vs. sustainable)—source [39]

	Convectional system	Sustainable system
Water	Limitless pure or contaminated	Freshwater is scarce
Nature	Dangerous resource sink for waste must be controlled	Partner limits to material and energy use restored and protected
Technology	Universal standards big systems requires expert knowledge	Context-specific variable scale expert knowledge required
Governance	Expert-led decision-making large utilities (public and private)-independent regulation	Democratic public participation and engagement adaptable to technology and scale
Capital	Capital intensive	Affordable and appropriate
Society	Consumption is private infrastructure serves society	Consumption is cultural infrastructure shapes society
Space	Centralized invisible outside urban form	Multiple scales distributed visible

resources. Application of decentralized systems supports the end users to access a renewable water supply. It also helps governments with reduced hassle regarding centralized water supply implementation [21]. Furthermore, rainwater harvesting reduces the demand for municipal water resources and consumption. It mitigates the harmful consequences of urban stormwater run-off. Its application in accordance with appropriate education, planning, and public awareness is essential [19].

5. Summary and discussions

This research provided an overview on the existing rainwater harvesting systems. Appropriate design and configuration schemes of rainwater harvesting systems highlight the importance of focusing on water storage tank sizes according to regional circumstances, roof surface measurements, rainwater stipulation, and the household population. Furthermore, rooftops are highlighted as the most promising candidate for rainwater harvesting implementations specifically in urban areas.

The resultant harvested roof-based rainwater quality is in accordance with rooftops typologies. This research expresses the negative impact of typical green roofs on quality of the collected rainwater. They filter some critical nutrients and add light and heavy metals and various other contaminating elements to the harvested rainwater.

Eventually, governments are encouraged to promote rainwater harvesting systems in areas with high success potential based on climatic conditions and rainfall patterns. In less ideal conditions, the best approach is to endorse these systems in public buildings and infrastructures, rather than more generally across private residences, etc. Ultimately, governments are advised to educate the target population of both the immediate and long-term benefits of these systems based on pay-back period compared to the environmental sustainability potentials of decentralized water supply and consumption resource.

References

[1] E. Ghisi, D.d.F. Tavares, V.L. Rocha, Rainwater harvesting in petrol stations in Brasília: Potential for potable water savings and investment feasibility analysis, Resour. Conserv. Recycl. 54(2) (2009) 79–85.

[2] UNEP, An Overview of the State of the World's Fresh and Marine Waters, second ed., World Bank, 2008.

[3] Bureau, USC 2014; Available from:https://www.google.com/publicdata/explore?ds=d5bncppjof8f9_andctype=landmet_y=er_h2o_intr_pc#!ctype=landstrail=falseandbcs=dandnselm=handmet_y=sp_pop_totlandscale_y=linandind_y=falseandrdim=regionandifdim=regionandtdim=trueandhl=en_USanddl=en_USandind=false. Accessed [November 30, 2014].

[4] M.V. Vargas-Parra, G. Villalba, X. Gabarrell, Applying exergy analysis to rainwater harvesting systems to assess resource efficiency, Resour. Conserv. Recycl. 72 (2013) 50–59.

[5] R. Farreny, T. Morales-Pinzón, A. Guisasola, C. Tayà, J. Rieradevall, X. Gabarrell, Roof selection for rainwater harvesting: Quantity and quality assessments in Spain, Water Res. 45(10) (2011) 3245–3254.

[6] C. Santos, F. Taveira-Pinto, Analysis of different criteria to size rainwater storage tanks using detailed methods, Resour. Conserv. Recycl. 71 (2013) 1–6.

[7] L. Partzsch, Smart regulation for water innovation—the case of decentralized rainwater technology, J. Clean Prod. 17(11) (2009) 985–991.

[8] M.A. Imteaz, A. Ahsan, A. Shanableh, Reliability analysis of rainwater tanks using daily water balance model: Variations within a large city, Resour. Conserv. Recycl. 77 (2013) 37–43.

[9] S. Ward, F.A. Memon, D. Butler, Performance of a large building rainwater harvesting system, Water Res. 46(16) (2012) 5127–5134.

[10] M.H. Rashidi Mehrabadi, B. Saghafian, F. Haghighi Fashi, Assessment of residential rainwater harvesting efficiency for meeting non-potable water demands in three climate conditions, Resour. Conserv. Recycl. 73 (2013) 86–93.

[11] F.A. Abdulla, A.W. Al-Shareef, Roof rainwater harvesting systems for household water supply in Jordan, Desalination 243(1–3) (2009) 195–207.

[12] D.J. Sample, J. Liu, Optimizing rainwater harvesting systems for the dual purposes of water supply and runoff capture, J. Clean Prod. 75 (2014) 174–194.

[13] C.B. Mendez, J.B. Klenzendorf, B.R. Afshar, M.T. Simmons, M.E. Barrett, K.A. Kinney, M.J. Kirisits, The effect of roofing material on the quality of harvested rainwater, Water Res. 45(5) (2011) 2049–2059.

[14] A.S. Vieira, C.D. Beal, E. Ghisi, R.A. Stewart, Energy intensity of rainwater harvesting systems: A review, Renewable Sustainable Energy Rev. 34 (2014) 225–242.

[15] A.Y. Katukiza, M. Ronteltap, C.B. Niwagaba, F. Kansiime, P.N.L. Lens, Grey water treatment in urban slums by a filtration system: Optimisation of the filtration medium, J. Environ. Manage. 146 (2014) 131–141.

[16] C.M. Chew, M.K. Aroua, M.A. Hussain, W.M.Z.W. Ismail, Practical performance analysis of an industrial-scale ultrafiltration membrane water treatment plant, J. Taiwan. Inst. Chem. Eng. (DNLM) 46 (2014) 132–139.

[17] E. Eroksuz, A. Rahman, Rainwater tanks in multi-unit buildings: A case study for three Australian cities, Resour. Conserv. Recycl. 54(12) (2010) 1449–1452.

[18] A. Khastagir, N. Jayasuriya, Optimal sizing of rain water tanks for domestic water conservation, J. Hydrol. 381(3–4) (2010) 181–188.

[19] M.P. Jones, W.F. Hunt, Performance of rainwater harvesting systems in the southeastern United States, Resour. Conserv. Recycl. 54(10) (2010) 623–629.

[20] M.A. Imteaz, A. Shanableh, A. Rahman, A. Ahsan, Optimisation of rainwater tank design from large roofs: A case study in Melbourne, Australia, Resour. Conserv. Recycl. 55(11) (2011) 1022–1029.

[21] J.Y. Lee, J.-S. Yang, M. Han, J. Choi, Comparison of the microbiological and chemical characterization of harvested rainwater and reservoir water as alternative water resources, Sci. Total Environ. 408(4) (2010) 896–905.

[22] Q. Zhang, X. Wang, P. Hou, W. Wan, R. Li, Y. Ren, Z. Ouyang, Quality and seasonal variation of rainwater harvested from concrete, asphalt, ceramic tile and green roofs in Chongqing, China, J. Environ. Manage. 132 (2014) 178–187.

[23] K. Vijayaraghavan, U.M. Joshi, R. Balasubramanian, A field study to evaluate runoff quality from green roofs, Water Res. 46(4) (2012) 1337–1345.

[24] W. Ahmed, F. Huygens, A. Goonetilleke, T. Gardner, Real-time PCR detection of pathogenic microorganisms in roof-harvested rainwater in Southeast Queensland, Australia, Appl. Environ. Microbiol. 74(17) (2008) 5490–5496.

[25] J. Zobrist, S.R. Müller, A. Ammann, T.D. Bucheli, V. Mottier, M. Ochs, R. Schoenenberger, J. Eugster, M. Boller, Quality of roof runoff for groundwater infiltration, Water Res. 34(5) (2000) 1455–1462.

[26] J.Y. Lee, G. Bak, M. Han, Quality of roof-harvested rainwater—Comparison of different roofing materials, Environ. Pollut. 162 (2012) 422–429.

[27] M. Sturm, M. Zimmermann, K. Schütz, W. Urban, H. Hartung, Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia, Phys. Chem. Earth Parts A/B/C 34(13–16) (2009) 776–785.

[28] A. GhaffarianHoseini, N.D. Dahlan, U. Berardi, A. GhaffarianHoseini, N. Makaremi, M. Ghaffarian Hoseini, Sustainable energy performances of green buildings: A review of current theories, implementations and challenges, Renewable Sustainable Energy Rev. 25 (2013) 1–17.

[29] S. Cook, A.K. Sharma, T.R. Gurung, Evaluation of alternative water sources for commercial buildings: A case study in Brisbane, Australia, Resour. Conserv. Recycl. 89 (2014) 86–93.

[30] M. Jänicke, Ecological modernisation: New perspectives, J. Clean Prod. 16(5) (2008) 557–565.

[31] A. GhaffarianHoseini, A. GhaffarianHoseini, N. Makaremi, M. GhaffarianHoseini, The concept of zero energy intelligent buildings (ZEIB): A review of sustainable development for future cities, BJECC 2(4) (2012) 339–367.

[32] T.L.C. Moore, W.F. Hunt, Predicting the carbon footprint of urban stormwater infrastructure, Ecol. Eng. 58 (2013) 44–51.

[33] J.Y. Lee, H.J. Moon, T.I. Kim, H.W. Kim, M.Y. Han, Quantitative analysis on the urban flood mitigation effect by the extensive green roof system, Environ. Pollut. 181 (2013) 257–261.

[34] R.N. Hilten, T.M. Lawrence, E.W. Tollner, Modeling stormwater runoff from green roofs with HYDRUS-1D, J. Hydrol. 358(3–4) (2008) 288–293.

[35] U. Berardi, A. GhaffarianHoseini, A. GhaffarianHoseini, State-of-the-art analysis of the environmental benefits of green roofs, Appl. Energy 115 (2014) 411–428.

[36] A. GhaffarianHoseini, R. Ibrahim, M.N. Baharuddin, A. GhaffarianHoseini, Creating green culturally responsive intelligent buildings: Socio-cultural and environmental influences, INBI 3(1) (2011) 5–23.

[37] L. Domènech, D. Saurí, 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. Clean Prod. 19(6–7) (2011) 598–608.

[38] A. Rahman, J. Keane, M.A. Imteaz, Rainwater harvesting in Greater Sydney: Water savings, reliability and economic benefits, Resour. Conserv. Recycl. 61 (2012) 16–21.

[39] S. Bell, Renegotiating urban water, Prog. Planning 96 (2014) 1–28, doi: http://dx.doi.org/10.1016/j.progress.2013.09.001.