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GENERAL ARTICLE

ISSUES AND CHALLENGES IN RAINWATER HARVESTING FOR POTENTIAL POTABLE AND NON-POTABLE WATER PRODUCTION

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ABSTRACT

This article reviews recent literatures on issues and challenges in rainwater harvesting and its potential application for potable and non-potable uses. Vast articles published between 1982 and 2019 were found, which some of them revealing concerns on various issues regarding the factors affecting the implementation of rainwater harvesting, in fulfilling the needs for rainwater as the alternative water resource. More research should be conducted in the future, in addressing the issues. While the practice of rainwater harvesting is back to track, the degree of its modern implementation varies greatly across the globe, and often relates with problems in maximizing the potential benefits and system efficacy. Future research should be more devoted to the understanding of technological and non-technological issues, as well as the factors effecting the quantity and quality of rainwater, to improve the rainwater harvesting system, therefore increase the system efficacy and community acceptance.

KEYWORDS

Rainwater harvesting, sustainable urban water systems, stormwater management, water conservation

1. INTRODUCTION

Rainwater harvesting is defined as a method or process of collecting rainwater that falls upon roof surface, routed to a storage facility, and being used later for productive purposes (Kahinda et al., 2008; Debusk and Hunt, 2014). Rainwater harvesting is a vital technology option in improving water supply (Saidan et al., 2015). This rainwater collection method plays a crucial role in increasing water security for a country, has led to substantial researches in the past, and its technical and economic aspects have been long debated (Amos et al. 2016). In addition, this method has also been developed in thousands year back to ancient societies and has been used in various activities such as agriculture and construction in urbanized areas, and has a history of used in semi-arid countries (DeBusk and Hunt, 2014; Liaw and Chiang, 2014; Saidan et al., 2015). Water harvested from rainwater provides main source of both potable and non-potable water (i.e. toilet flushing, irrigation and car washing), and has recently become important alternative water resources to address shortage of water in urban and sub-urban areas especially in developed countries (Ahmed et al., 2011; Campisano et al., 2013; Melville-Shreeve et al., 2016).

The advantages of using rainwater harvesting method include (i) reducing the rely on the conventional domestic water supply, (ii) reducing stormwater runoff that could degrade drainage ecosystem, and (iii) providing an alternative water supply during times of water restrictions due to shortage of rainfall event or polluted surface water for water intake (Ahmed et al., 2011). In addition, most of the sustainable building codes recommend installation of rainwater harvesting system in buildings as part of integrated water management strategies in portable water savings, flood mitigation in urban catchments and extensive impervious areas, reducing nutrient loads to waterways and increasing lifespan of constrained centralized water distribution infrastructure due to reduction of water demand (Vieira et al., 2014).

A number of factors, however, may affect the rainwater harvesting system in terms of quantity and quality (Pandey et al., 2003; Schets et al., 2010; Ahmed et al., 2011; Liang and van Dijk, 2015; Amos et al., 2016; Hofman-Caris et al., 2019). One of the shortcomings is the lack of appropriate guidelines specifying the use of harvested rainwater for both potable and non-potable purposes, particularly on the risk of chemical and microbiological contaminants throughout the usage of harvested rainwater (Ahmed et al., 2011). The literature review was based on the issues as well as the challenges in sustaining the practice of rainwater harvesting across the country. The most relevant studies governing the issues related to quantity and quality of rainwater, technical and non-technical, with possible solutions to the pointed issues. Thus, this review aims to integrate issues and challenges related to rainwater harvesting, and provide insights of possible solutions in overcoming the issues and to make rainwater harvesting efficient, especially in tropic conditions.

2. RAINWATER HARVESTING SYSTEM

Three key elements that must have in a rainwater harvesting system are (i) a collection surface, (ii) guttering and (iii) a storage tank. The essence of this rainwater harvesting system is during the interception of the rainwater (Thomas, 1998). Basic design of an above-ground rainwater harvesting system that is commonly applied is depicted in Figure 1. Contamination may take place in the air, during the collection at the roof surface, or even in the storage, either by airborne dissolved chemical or biological pathogens. Table 1 simplified potential factors that can affect the practice and efficacy of rainwater harvesting system.

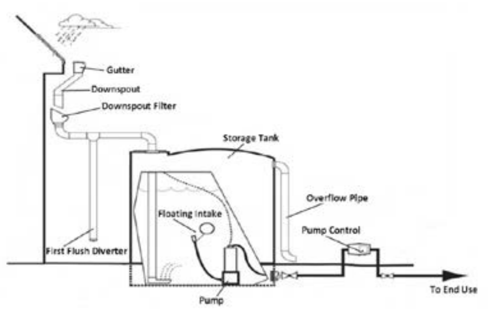

Figure 1: Example of an above-ground rainwater harvesting system (Source: Debusk and Hunt, 2014)

Table 1: Factors affecting the implementation and efficiency of rainwater harvesting system

Factors		References
Quantity	Climate change and atmospheric condition	Farreny et al., 2011; Pandey et al., 2003; Hofman-Caris et al., 2019; Mohammed et al., 2006; Ayob and Rahmat, 2017; Debusk and Hunt, 2014
Quality	Microbiological contamination	Ahmed et al., 2011; Schets et al., 2010; Thomas, 1998; Hofman-Caris et al., 2019; Liang and van Dijk, 2015; Mahmoud et al., 2018
	Chemical contamination	Schets et al., 2010; Thomas, 1998; DeBusk and Hunt, 2014; Hofman-Caris et al., 2019; Farreny et al., 2011
Technical	Energy consumption	Vieira et al., 2014
	Design aspects	DeBusk and Hunt, 2014; Campisano et al., 2017; Teston et al., 2018
Non-technical	Installation and maintenance cost	Amos et al., 2016; Hofman-Caris et al., 2019; Liang and Dijk, 2015; Melville-Shreeve et al., 2016; Lani et al., 2018
	Awareness and understanding	Mohamad et al., 2014; Liang and Dijk, 2015; Soler et al., 2018; Cochran and Ray, 2009

2.1 Energy consumption and design of rainwater harvesting system

The enhancement of the rainwater harvesting system energy performance will likely consent an increase of concession among utility providers (i.e., water and electrical power) at a building scale, which in turn improve the development of water and energy resilient in future. The rainwater harvesting system includes pumping and UV systems, that consider pump and UV conversion efficiencies, total number of start-ups, usage of standby energy, as well as rainwater consumption patterns (Vieira et al., 2014; Lani et al., 2018). Besides the rainwater harvesting system and its energy performance, type of town water back-up system is also important. Indirect pumped distribution systems with automatic switches are more energy efficient from trickle top-up to header tanks (Vieira et al., 2014).

Design of a rainwater harvesting system closely relates to the quality of harvested rainwater (Hofman-Caris et al., 2019). The pH of the harvested water, for instance, is affected by the roof material; iron-zinc, aluminum, galvanized iron, zinc or wood shingles (Mendez et al., 2011). Variety of roofing materials comprised of alkaline materials such as concrete, gravel, asphalt shingles, clay, or pantile will prompt to a significant increase in the pH of the harvested rainwater (Föster 1999; Mendez et al., 2011). Meanwhile, low pH of running rainwater over the roof surface increases the reactivity between the rainwater and the roofing materials (especially metal type roofing) and particulates accumulated on the roof surface from atmospheric deposition will in turn caused a leaching of chemicals and metals, and eventually will increase the possibility of labile species fraction (Hofman-Caris et al., 2019).

2.2 Installation and maintenance cost

The price of installation and maintenance is one of the crucial issues regarding rainwater harvesting since water savings are the primary benefit of the rainwater harvesting system in order to ensure rainwater tank able to recover the investment costs. Predictions of future water tariff are often used to calculate the payback periods (Hofman-Caris et al., 2019), presuming that rainwater can be collected from built and paved surface areas (Amos et al., 2016). In addition, the quality of harvested rainwater supposedly be better than the quality of surface water, that still contain pharmaceutical residues and microbial contaminations (Hofman-Caris et al., 2019).

Predictions of future water tariff are often used to calculate the payback periods (Hofman-Caris et al., 2019). Rainwater harvesting can potentially be implemented for commercial building as it offers large catchment areas and big scale of water consumption, which can lead to a high spending due to increasing water tariff. Harvested rainwater in a commercial building can be used for toilet flushing, pavement washing and garden irrigation (Lani et al., 2018). Considering the economic benefits and building sustainability, therefore in Malaysia, it is timely to evaluate commercial buildings and investment of rainwater harvesting.

Waterfall (2006) suggested a checklist for the maintenance of a rainwater harvesting system, which includes ensuring collection areas free from debris, controlling and preventing erosion and blocking the erosion trails, cleaning and repairing the water channels, cleaning and repairing dikes, berms and moats, keeping gutters and downspouts free from debris, flushing debris from the bottom of storage containers, and cleaning and maintaining filters including drip filters. In reducing cost of installation and maintenance, a rainwater harvesting system powered by solar and gravity irrigation can be implemented (Leib et al., 2020). The study suggested gravity flow can be benefited in a good slope area for water distribution, and solar powered pumping can be integrated in the rainwater harvesting system in poor slope area.

3. Quantity and Quality of Rainwater

Other than energy intensities and installation and maintenance cost, major challenges in implementing rainwater harvesting can also be evolved on the interactions of many factors which include both quantity and quality of the rainwater. Issues regarding rainwater quality mainly arise from contamination at the collection stage, when rainwater is in contact with hard surface roofing materials, which are often covered with contaminants from dry (e.g., dust and particulates) and also wet precipitation (e.g., rain and fog), animal urine and feces, and plant (e.g., debris). These contaminations will then be accumulated in the collected rainwater (Thomas 1998; Hofman-Caris et al., 2019).

Also, condition of acid rain, will in turn impacts on the dissolution of heavy metals and carbon from roofing materials, which can result in worsen quality of harvested rainwater. Hence the type of roof surface, as well as the angle and direction of the roof will also need to be taken into consideration, as it will affect the physico-chemical parameters, concentration of ions, heavy metals and biological parameters of the collected rainwater (Hofman-Caris et al., 2019). In other words, health risk appears to be related to bad material selection and maintenance of the rainwater harvesting system. Regular cleaning of the system could prevent the growth of microorganisms, and sources of contamination such as direct contamination from the harvesting surface and system, and regrowth of bacteria in the storage tank can be distinguished (Hofman-Caris et al., 2019).

3.1 Chemical and microbiological contamination

Common problems with roof harvested rainwater are related to roofing issues as debris, trees overhang roofs and bird droppings, which can silt up contaminants or deoxygenate water stores, discoloration of water and eventually can lead to diseases (Thomas, 1998). Few studies reported on sporadic gastroenteritis associated with the consumption of untreated roof harvested rainwater (Hofman-Caris et al., 2019). Studies between 1992 and 2008 attempted to identify the inherent risk of infection and highlighted the need for evaluating actual health risks from potable and non-potable uses of roof harvested rainwater, through Quantitative Microbial Risk Assessment (QMRA); a four-step probabilistic tool for estimating the human risk associated with defined scenarios from exposure to specified pathogens (Heyworth et al., 2006; Chubaka et al., 2018).

Major significant issue with regard to untreated rainwater harvesting for potable usage is the potential public health risks associated with microbial pathogens (Ahmed et al., 2011). Harvested rainwater can be contaminated with microbial pathogens via roof runoff that contacted with faeces of birds, insects, reptiles or mammals that have access to the roof, as well as other organic debris deposited on the roof and gutter (Ahmed et al., 2012).

Thus, however, there is also a general community perception that rainwater is safe to drink without having to undergo prior treatment. This statement is supported by a study in South Australia revealed a survey of gastroenteritis among 4 to 6 year-old children who consumed rainwater or treated mains water that suggested harvested rainwater poses no increased risk of gastroenteritis as compared to mains water (Heyworth et al., 2006). In contrast, Chubaka et al. (2018) suggested there is a need for more research investigating the risk posed by opportunistic pathogens, particularly in susceptible populations.

3.2 Climate change and atmospheric condition

Climate change can be one of the factors affecting the performance of rainwater harvesting as it changes the availability, quantity and quality of the water resources, which in turn can impact the whole cycle of water supply. Malaysia and other Southeast Asian countries receive high intensities if annual rainfall during monsoon season (Ayob and Rahmat, 2017). In addition, nature of rainfall event in Peninsular Malaysia can be categorized into three major seasons; which are southwest monsoon between May and September, northwest monsoon between November and March, and inter monsoon during the transition period from the Southwest Monsoon season to the Northeast Monsoon season or vice versa in October and April each year (Lani et al., 2018). Southeast Asian countries also often associated with water shortage during El Nino; natural phenomenon that occurs in Pacific Ocean when warm waters of the western coast of South America replaces the colder nutrient rich waters and cause impacts on the weather patterns such as increase in temperature between 0.5 and 2.0 degrees Celsius, and reduce the amount of rainfall (Ayob and Rahmat, 2017).

A group reserchers suggested that future studies should concentrate on cultural responses to climate change with economic implications such as the role of rainwater harvesting in plant and animal domestication that may have impacted the evolution of cultural landscapes, agroecosystems and early agriculture. This is to consider the accessible freshwater runoff which is appropriated for human use, population that is lack access to clean drinking water and lack of basic sanitation services, the rapid growth of human population that will increase the amount of accessible freshwater, and also climate change that will impact on the general intensification of the earth's hydrological cycle in the coming centuries.

4. RESULTS AND DISCUSSION

We describe the results of a literature study on addressing several challenges by identifying potential factors affecting the quality, quantity and the efficacy of rainwater harvesting system. Findings of this study will therefore be used to suggest potential treatments for harvested rainwater that are more robust, in ensuring safe water for potable and non-potable purposes can be produced. For instance, in terms of quality, Mohammed et al. (2006) suggested usage of nanofiltration to remove water hardness, natural organic material, and micropollutants such as pesticides, viruses, bacteria, salinity, nitrates and arsenic.

In terms of quantity, combining rainwater harvesting with provided and distributed regular central drinking water as a back-up system was seen to be the most recommended solution regarding this issue. Nonetheless, in order to guarantee sufficient water supply for domestic uses during all seasons throughout the year, including periods with shortage of rain, and for continuous supply of harvested rainwater, the capacity of each treatment process would have to be identical to the existing (regular) system (Hofman-Caris et al., 2019). Besides, it is worthwhile to initiate efforts from the perspective of the percentage of reliability that is highly influenced by temporal and spatial distribution of rainfall, size of catchment area, the capacity of storage tank, and the water demand itself (Lani et al., 2018). An integrated perspective of traditional knowledge in adapting the shortage of harvested rainwater, is often useful to comprehend vulnerability and adaptation to environmental stresses at local scale, and therefore the complexities of the nature can be fully captured (Lani et al., 2018).

From the government point of view, an insightful policy could help the promotion of rainwater harvesting as a major concern on the adapting strategy in achieving global security and sustainability of water resources, particularly in this anthropogenic climate change era (Pandey et al., 2003). Meanwhile, Woltersdorf et al. (2014) recommended government to initiate funding for the rainwater harvesting infrastructure and the maintenance costs, as the start-up efforts of rainwater harvesting. A continuous and systematic support to local innovations on rainwater harvesting such as simple local techniques (i.e., ponds and earthen embankments) could provide a promising substantial amount of harvested rainwater (Pandey et al., 2003).

5. CONCLUSIONS

In a nutshell, climate and water policies would require to be rationalized to promote rainwater harvesting in the water-stressed regions of the world, and to be discussed critically to notice the worth of rainwater harvesting as an adaptation to climate change, particularly in urbanized areas where water resources are recklessly lessening due to swift increase in population and unrestricted use of water towards a sustainable management of water resources. The outcomes of this literature study highlighted an important significance for local governments and urban planners in designing and planning future cities, therefore, new sustainable development of stormwater roof runoff could be promoted in terms of resource availability and quality, and fostering rainwater harvesting system. In this intensive climate change era, with an insightful policy, rainwater harvesting can be encouraged as part of the strategies in achieving sustainability of conservation of water resources. Major concern on the implementation of rainwater harvesting in future is to provide economically potable use of harvested rainwater with minimum treatment.

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