Article

A Review of Roof and Pond Rainwater Harvesting System: the Design, Performance and Way Forward

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Abstract: This paper reviews the design and component of two types of RWHS, namely roof harvesting system (RHS) and pond harvesting system (PHS). The performance in terms of quantity and quality of collected rainwater and energy consumption for RWHS with different capacities were evaluated, as well as the benefits and challenges particularly in environmental, economic and social aspects. Presently, RHS is more commonly applied but its effectiveness is limited by its small scale. The PHS is of larger scale and has greater potentials and effectiveness as an alternative water supply system. Results also indicate the many advantages of PHS especially in terms of economics, environmental aspects and volume of water harvested. While RHS may be suited to individual or existing buildings, PHS has greater potentials and should be applied in newly developed urban areas with wet equatorial climate.

Keywords: domestic water demand; pond harvesting system; roof harvesting system; rainwater harvesting system; water scarcity; stormwater management

1. Introduction

In recent decades, water scarcity has become a global issue due to high water demand and depleting water availability [1]. Population growth, urbanization and industrialization have exerted tremendous pressures on water resources [2]. Furthermore, climate change has also exacerbated the decrease of water resources in many parts of the world, including the Mediterranean basin, Western United States and Southern Africa [3]. Climate change that has occurred with fluctuating temperatures tends to increase the frequency of drought and flooding periods [4], and this has led to a shortage of drinking water in some countries. For example, in the rural areas of Bangladesh, insufficient clean and safe drinking water is a serious problem, especially in southern coastal and eastern hilly areas [5]. In Malaysia, both droughts and floods have been experienced as a result of climate change [6-7]. Besides climate change, other aspects of environmental degradation such as deforestation, pollution and wetlands encroachment were also known to reduce human access to safe potable water, specifically in developing countries [8].

In this regard, the integrated water management (IWM) approach has been proposed as sustainable solutions for water scarcity within the development growth. IWM aims to protect the world environment, highlight the outcome in reducing the high dependency on water resources (surface water and groundwater) and high flow during flood event. This concept has been acknowledged by the United States Environmental Protection Agency (USEPA) and rainwater harvesting systems (RWHS) has been recognized as one of the approaches to achieve IWM [9]. RWHS is one of the potential solutions to solve the water scarcity problem and it is an effective technology

that enhances the performance of water supply [10]. The function of the system is solely to collect and save rainwater from rooftops, land surfaces, road surfaces or rock catchments [11]. This system is normally implemented either using a simple technique like pots, tanks and cisterns, or a complex technique, such as underground check dams. Collected rainwater will then be used as a non-potable water supply, for instance toilet flushing, laundry, irrigation and car washing [12]. Besides usage as a non-potable demand, harvested rainwater was also known as a renewable source for clean water and it can be applied for drinking water and potable demand [13-14].

There are two main categories of RWHS: pond harvesting system (PHS) and roof top harvesting system (RHS). RHS is a more familiar system being used and adopted worldwide, as many studies have been conducted on its function and performance, whereas the PHS application is still at an early stage. This is due to the design of the PHS that involves a bigger scale structure with a lot of factors that need to be taken into consideration, particularly the site selection [15]. However, due to the huge volume of rainwater harvested, the potential benefits of PHS are much greater than RHS and are yet to be fully discovered.

Therefore, the aims of this review paper are: (1) to review the types of RWHS design, its component and current performance in terms of rainwater quantity and quality as well as energy consumption; (2) to highlight the benefits and challenges in environmental, economic and social aspect of the RWHS application; and (3) to suggest the way forward in RWHS implementation and to identify the future potentials for PHS application.

2. System design and its components

2.1. Categories of RWHS

RWHS can be divided into two categories, namely roof harvesting system (RHS) and pond harvesting system (PHS). RHS is more well-known and has been applied in the countries such as Jordan [13], Spain [16], Italy [3], Australia [17], Ireland [18] and Malaysia [14, 19]. Harvested rainwater from the RHS is usually used to facilitate both non-potable and potable water demand. There are two types of storage tanks for RHS, which are aboveground (Figure 1a) and underground storage (Figure 1b). Meanwhile, the storage for PHS (Figure 2) is a reservoir that is normally located close to the crop field with the purpose of enhancing and supplementing irrigations [20], especially during the critical period of crop growth or for extending the growing season.
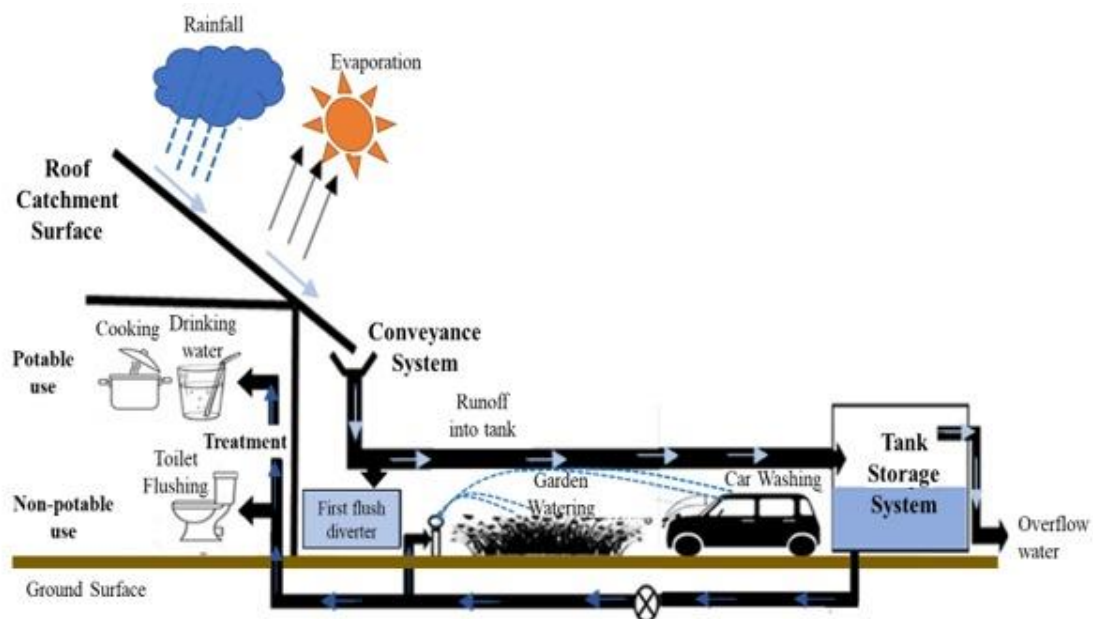
(a) Aboveground storage
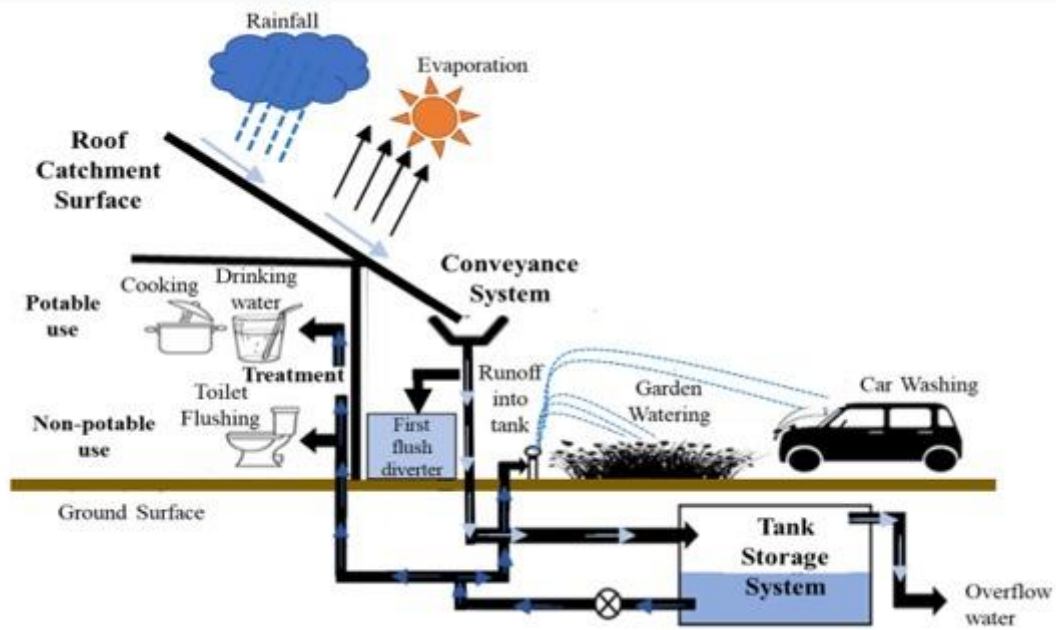
(b) Underground storage
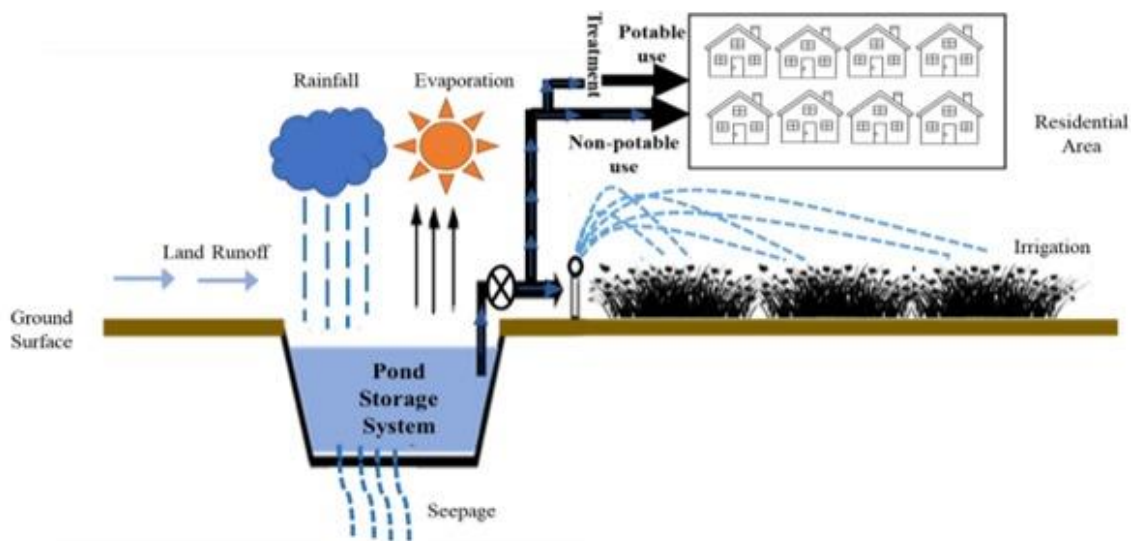
Figure 1. Design of roof harvesting system (RHS).

Figure 2. Design of pond harvesting system (PHS).

2.2. Components of RWHS

Generally, RWHS consists of three fundamentals components: catchment surface, conveyance system and storage system. In RWHS, catchment surface should be efficient in conveying surface runoff to accumulate into the storage tank or pond storage. RHS allows the collection of rainwater from the impervious surface of rooftop, while PHS harvests the rainwater from the pervious land surface. In RHS, the material used for the roof catchment surface will significantly influence the effectiveness and quality of collected rainwater. A roof type that is smooth, clean and impervious is preferable [18]. Some examples are asphalt shingles and flat tar roofs used in Ontario, Canada [21], clay tile and flat roof in Mediterranean landscape [16] and zinc roofs in Penang, Malaysia [22]. Unlike

RHS, PHS needs a catchment where the runoff can be easily captured such as the public domain, roads, or common land [23].

The function of the conveyance system in RHS is to transfer the rainwater from the rooftop catchment into the storage tank, which normally includes the gutters and downpipes. These gutters and downpipes are usually made with the different materials, for example plastic or metal in Jordan [13] or galvanized steel, stainless steel and fiberglass types in Ireland [18]. On the other hand, PHS does not require any conveyance system, as the runoff from the catchment area flows to the pond storage using gravitational force.

The storage system in RWHS is used to store the collected rainwater with minimal storage tank below hundred m³. For RHS, the storage tanks can be built in multiple ways with different materials, sizes and shapes. For example, plastic or concrete are used as a common storage tank material in Jordan [13], while cement-brick and metal are widely used in Ireland [18]. For aboveground storage tank (Figure 1a), it is good in minimizing the cost and it allows gravity flow in extracting the harvested rainwater [11]. The tank cleaning and detection of leakage and cracks are also easier as compared to underground storage tank. On the other hand, underground storage tank (Figure 1b) is better in maintaining the cool temperature of collected rainwater and it also preserves the aboveground space for other purposes. However, underground storage tank has some disadvantages in extracting the water (pump is needed), difficulty in detecting the leakage or crack, risk of contamination and higher cost of construction [18].

For most of the storage systems in PHS, the soil is used as the basic structure was designed with large pond storage ranging hundred to thousand m³. Unlike RHS that used enclosed storage systems, storage for PHS is an open system where the collected water is subjected to losses due to seepage into the subsurface of soil and evaporation. Therefore, additional methods need to be implemented, for example design with a lining, covered with corrugated items and built with a silt trap. The lining is built using plastic sheets or concrete with the purpose of minimizing the seepage losses of water captured into the soil subsurface [24]. Sometimes, the reservoir is covered by the corrugated plate or plastic sheet to decrease the evaporation losses. Other than that, PHS is also constructed with a lined or unlined silt trap which is located at the entrance of the storage system to avoid siltation and spillway that control the discharge of excess runoff [25].

2. Performance of RWHS

This section will discuss on the performance of RWHS, particularly water quantity, water quality, and energy consumption.

3.1. Water quantity

The performance of RWHS greatly depends on the quantity and temporal pattern of the rainfall [2]. The maximum benefits of RWHS can normally be achieved by considering the rainfall quantity but for similar roof area and water consumption rate, higher rainfall depth is more reliable. Therefore, to interpret the performance of RWHS, the daily water balance model is usually simulated instead of using annual rainfall [3]. The amount of harvested rainwater from the RHS depends on the runoff coefficient, which is the ratio of harvested rainwater to the total amount of rainwater falling on roof [26]. Different amount of rainwater harvested is mainly due to the different roof runoff coefficient, which is affected by the slope and type of roof.

Table 1 summarized the RHS case studies in developed and developing countries to compare their water supply capacity under different annual rainfall. It shows that the RHS can fulfill most of the domestic water demand and this helps to minimize the dependency on the conventional water supply. For case studies in developed countries such as Australia [17], Greece [27] and the New York [28], RHS is able to meet the domestic water demand between 50% to 90%, with the reported size of storage tank ranged between 5 to 76m³. For developing countries such as Bangladesh [29], Malaysia [14, 22, 30] and Southwestern Nigeria [31], the case studies shows that the domestic water demand that can be achieved is slightly lower than in developed countries (30% to 80%), although the reported size of storage tank is generally higher (except for Brazil [32] and Colombia [33]. For case study in

Jordan [13], the domestic water demand that can be achieved is extremely high, which is around 145%, due to larger storage area that is able to harvest high amount of rainwater from the rooftop and an open area of roads and parking lots.

Table 1. Summary of the RHS case studies in developed and developing countries for comparison of water supply capacity under different annual rainfall.

Country	Storage tank (m³)	Annual rainfall (mm)	Water supply	References
Developed countries				
Australia	50	1,318	meet 90% of domestic water demand	Cook et al. [17]
	5 - 20	973	meet 96% to 99% (wet seasons) and 69% to 99% (dry seasons) of toilet flushing and laundry	Hajani and Rahman [34]
France	5	760	saved 87% of toilet flushing water demand	Vialle et al. [35]
Greece	50	N/A	meet 50% of water demand for 5 people during dry period up to 133 days.	Londra et al. [27]
New York	5	1100	saved 53% of domestic water demand	Basinger et al. [28]
United Kingdom (UK)	5	N/A	meet 20-year period of average non-potable water demand	Melville-Shreeve et al. [36]
Washington D.C.	76	N/A	meet 77% of toilet flushing	Ghimire et al. [37]
Developing countries				
Bangladesh	N/A	3000	meet 20 liter/person/day of 5 people in each accommodation	Akter and Ahmed [38]
	30	2600	meet 30% to 40% of water demand	Bashar et al. [29]
	0.5 - 50	2400	meet 91.9% of drinking and cooking water demand	Karim et al. [39]
Brazil	2- 12	475- 3395	saved 12% to 79% of potable water demand	Ghisi et al. [32]
Colombia	2	1053	saved 44% of potable water demand	Oviedo-Ocaña et al. [33]
Jordan	2000	N/A	saved 125% to 145% of potable water demand	Awawdeh M. et al. [13]
Lebanon	N/A	765	meet 70% of the current deficit in the domestic water demand	Traboulsi and Traboulsi [40]
Malaysia	10	2400	saved 30% to 40% of water demand in common areas in 4 blocks of condominium comprising 965 units of apartments	Chan [22]
	10	2400	saved 40% to 50% of water demand in the School of Humanities, Universiti Sains Malaysia	Chan [14]
	160	1945	saved 58% of water demand for community of 200 houses	Hashim et al. [30]
Nigeria	N/A	3553	meet 80% of three-story building and 70% of bungalow	Nnaji and Mama [41]
Southwestern Nigeria	5	1,155.6	meet 90% of toilet flushing and 50% of laundry during the dry period.	Aladenola and Adeboye [31]

From the case studies, it shows that in most developed countries, RHS is implemented mainly for non-potable uses while for developing countries, it is also implemented for potable uses, often as drinking water. This difference of usage may be attributed to easy access to the conventional water supply, higher average income of consumers and affordable water tariffs in developed countries [42]. Overall, the harvested rainwater from RHS is able to meet more than half of the non-potable water demand, such as toilet flushing (around 70% to 90%) and laundry (between 50% to 90%) [31, 35]. For the potable use, the case study in Bangladesh showed that about 91.9% of drinking and cooking water demand has been achieved [39].

The case studies of PHS for dependency on irrigation and domestic demand in various countries is presented in Table 2. It is indicated that PHS can meet an average of 50% of the irrigation demand, with the pond storage capacity ranging from hundred to thousand m³ [37, 43-44]. The case study in Ethiopia showed that PHS can only fill up to 5% of domestic water demand, as the harvested rainwater was mainly used to fulfill the irrigation demand [45]. In contrast, for PHS case study in India, it can meet almost up to 100% of drinking water demand, at 40 litre cubic per demand (lcpd) of 1632 population due to the fact that PHS was constructed as drinking water pond [25].

The case studies have shown that the opened systems of PHS could cause massive water loss through seepage and evaporation. For example, the water loss in Eastern India is around 8% (evaporation) and 30% (seepage) [46] and in Laikipia around 30% to 50% [47]. According to [48], the smaller the size of PHS, the higher the seepage loss compared to evaporation loss and vice versa for the larger size of PHS. This shows that inappropriate selection of the targeted site, such as soil type and climate condition will cause a higher amount of water loss [23]. Therefore, by using the additional method of pond lining, such as plastic or geo-membrane in Ethiopia [45] and retaining wall in India [25], the amount of water loss can be reduced.

For tropical climate country such as Malaysia that has relatively rich of water resources (annual rainfall is estimated 2400mm in peninsular area) was never been situated in water crisis issues for the past few decades. However, the climate change is predicted to decrease the future rainfall in several states in Malaysia to as low as 32% to 61% of average monthly rainfall, particularly during the dry season from May to August [49]. Therefore, many studies and research have been conducted on RHWS to reduce the dependency on water resources and hold back water crisis especially during the dry seasons, but most of the studies only focused the RHS application [14, 22, 30] and the potential of PHS application in Malaysia has not been fully discovered although it has bigger storage capacity to accommodate the larger community.

With the current application of PHS which was only restricted rural areas and mainly used for irrigation, there is a need to explore the PHS application in urban areas, especially with the current new development that is emphasized on nature-based solutions (NBS), a concept defined by International Union for Conservation of Nature as "a sustainability of natural and ecosystem while providing benefits for human well-being" [50]. One of the examples of NBS project is constructed wetlands, which has been applied as HYDROUSA project in Mediterranean regions [51], Gorla Maggiore Wetland in northern Italy [52] and BIOECODS (Bio-Ecological Drainages System) Project in Malaysia [53]. Taking BIOECODS as example, the system consisting several types of ponds which are dry pond, wet pond, detention pond, wetland and recreational pond [53] was serving function to reduce runoff rates, runoff volume and pollutant load. The recreational pond that detained of treated rainwater is the great potential as PHS application to fulfill the domestic water demand. Under the same practices of BIOECODS, the current policy of every new development in Malaysia should allocate 3% of the 10% green area [54] for the pond which is another potential to maximize the usage as PHS application as well as saved of the domestic water demand and it is applicable to be practices in the other countries of tropical climate.

Table 2. Summary of the water supply capacity of PHS case studies.

Country	Storage area (m³)	Annual rainfall (mm)	Water supply		Additional method	References
			Irrigation	Domestic		
Bangladesh	1500 - 6500	492	meet 43% of water demand	N/A	N/A	Hasan et al. [55]
Ethiopia	102	N/A	meet 45% of seedling, fruit production and 50% of livestock watering	meet 5% of water demand	Plastic lining or geo-membrane	Teshome et al. [45]
Guatemala	2500	1166	424,070.81 m³ total volume of harvested	N/A	N/A	Wu et al. [44]
India	23530	836	N/A	23,000 m³ meet of drinking water demand for the 1632 population	Retaining wall	Farook et al. [25]
	1200	549	5000 m³ total volume of harvested	N/A	N/A	Ramotra and Gaikwad [43]
Kenya	30 - 100	280 - 1100	50 m³ total volume of harvested to irrigate a kitchen garden	N/A	N/A	Ngigi et al. [47]

3.2. Water quality

The quality of harvested and stored rainwater is influenced by the behavior of individual areas, such as topography, weather, and sources of pollution [56]. Harvested rainwater could be utilized as a water supply if the water quality parameter satisfies the acceptable level. Therefore, regular monitoring is needed as it has the potential for health risk due to the existence of chemical, physical and microbiological contaminants, which is presented in the case studies summarized in Table 3.

Table 3. Summary of water quality and treatment of RHS and PHS case studies.

Country	Water quality	Water treatment	References
Roof Harvesting System (RHS)			
Bangladesh	meet the requirement except pH	low-cost flushing device	Alam et al. [5]
	suitable for drinking water without any treatment in Dhaka areas	sand filter	Islam et al. [57]
Canada	contaminated with zinc and cadmium	• first-flush device • UV disinfection • slow sand filtration storing rainwater at temperature (50–70 ^{0}C)	Despins et al. [21]
Colombia	N/A	first flush diversion device	Oviedo-Ocaña et al. [33]
Delta State, Nigeria	meet the requirement for physiochemical and biological parameter of WHO standard but	N/A	Efe [58]

	treatment is needed for pH, TSS, Fe and color		
Greece	meet the requirement for physical and chemical parameter for drinking water except microbial indicators (total coliforms, E. coli and enterococci)	chlorination	Sazakli et al. [56]
Ireland	contaminated with three bacterial indicators (coliforms, E. coli and enterococci)	• filtration system • chlorination	Li et al. [18]
Jordan	meet the requirement of WHO standard except for nitrates and biological contaminants	N/A	Awawdeh M. et al. [13]
Jordan	meet the requirement of WHO standards for drinking water except fecal coliform	first flush device	Abdulla and Al-Shareef [11]
Malaysia	meet the requirement for potable use, except for E. coli	• first flush device • disinfection	Shaheed and Mohtar [59]
Malaysia	relatively clean but required treatment for potable uses.	• filtration with pH adjustment • chlorination	Hafizi Md Lani et al. [2]
United States (US	• not suitable for drinking water (exceed USEPA standards for pH, fecal coliforms, aluminum, lead and zinc) • suitable for non-potable use with 200 cfu fecal coliforms	• filtration • UV disinfection	DeBusk et al. [60]
Northern Ethiopia	not suitable for drinking water	N/A	Taffere et al. [61]
Palestinian	not suitable for drinking water (contaminated with coliforms and heterotrophic bacteria)	• regularly cleaning • chlorination • first flush device	Daoud et al. [62]
Portugal	N/A	• first flush device • filtration	Silva et al. [63]
Zambia	suitable for drinking water but concerned with its taste and debris	N/A	Handia et al. [64]
Pond Harvesting System (PHS)			
India	for potable uses, contaminated with excess iron, turbidity and fecal coliform	chlorination	Farook et al. [25]
Guatemala	suitable for drinking water and non-potable use	N/A	Qi et al. [65]
South Africa	for non-potable uses, contaminated with high value of total suspended solid and E. coli	• filtration • UV disinfection	Rohrer and Armitage [66]

Based on Table 3, the rainwater quality of both RHS and PHS in most of the case studies does not meet the World Health Organization (WHO) water quality standard, especially the biological parameter. The storage systems for both RHS and PHS can be potentially contaminated by the biological parameter, meanwhile the rooftop catchment of RHS may contribute to chemical

contamination and land surface catchment of PHS may lead to physical contamination. For RHS, major pollutants detected from storage of harvested rainwater are microorganism such as E. coli, coliforms and enterococci [11, 18, 56, 62, 67] and fecal by birds and mammals [18]. Other contaminations were also found, especially heavy metals, such as Pb and Zn that came from the roof material and nutrient ions from the polluted atmosphere [13, 21, 68]. These levels generally exceeded the acceptable standard of water quality for non-potable use, recreational and industrial.

One of the main factors that contribute to the pollution of harvested rainwater is the improper way of storage, such as overflow and unhygienic rainwater systems. The coliform group can be easily detected in RHS and PHS after collection and storage, due to the potential change in the water quality within the long period of storage [69]. Microbial contamination will be the main problem if the water is used as the drinking water. For RHS case studies in Bangladesh, Canada, Germany, Greece, Jordan, Malaysia, Palestinian and Zambia shows that the collected rainwater meets the safe drinking water standards, except the biological parameter, which still required further treatment [2, 11, 21, 56-57, 59, 62, 64]. For PHS case studies, most of the harvested rainwater is unsafe for drinking purposes, especially in Dindigul District, India, the harvested rainwater had exceeded the allowable standard for turbidity, iron and fecal coliform [25] and in South Africa, the water is contaminated with high level of TSS and E. coli [66].

In United States, several guidelines by United Stated Environmental Protection Agency (USEPA) were used to regulate the water supply standards. The Guidelines for Water is used to facilitate the developments related to water reuse, including RWHS and serves as an authoritative reference on water reuse practices [9], and 2017 Potable Reuse Compendium is used to complement the 2012 Guidelines and discuss the current practices and methods used in potable reuse [70], while the Managing Wet Weather with Green Infrastructure Municipal Handbook - Rainwater Harvesting Policies is used to assist the local officials to implement RWHS in their communities [71]. According to the guidelines, for potable use, the requirement should be zero amount for total and fecal coliforms, protozoan cysts and virus with less than 1 Nephelometric Turbidity Units (NTU) of turbidity. Meanwhile, for non-potable use, there is no requirement for outdoor use but for indoor use, the minimum requirements are less than 500 colony forming units (cfu) for total coliforms and 100 cfu for fecal coliforms per 100mL [71]. From Table 3, study by [60] showed that the harvested rainwater does not meet the USEPA drinking water for pH, fecal coliforms, aluminum, lead and zinc but the amount of fecal coliform (200 cfu) allows human contact towards the harvested rainwater for non-potable use.

Other factors that need to be considered are rainfall events and size of storage tanks. In RHS application, the harvested rainwater showed better water quality through the smaller and more frequent rainfall events [72]. The usage of smaller storage system in RHS as compared to PHS gives the advantages to allow the collection of all rainfall events and flushed away the pollutant through the first flush device [73]. However, the quality of harvested rainwater will deteriorate through the extreme events that occurred from the worst climate change. The drought seasons will enhance the accumulation of pollutants on the roof including heavy metals from polluted air and high capacity of accumulated water during flood events will promote the mosquitoes breeding [74]. Under similar circumstances, the large storage system of PHS application will caused the rainwater quality became worse due to development of algae bloom and reduction of dilution capacity (point sources) [75] during drought seasons as well as the rainwater that carried away of harmful contaminations such as pesticides, oil and animal waste during the flood flash. Furthermore, the location of PHS at downstream has caused all the pollutants from upstream will directly flow into the pond storage within the catchment area. Although the quality of the rainwater harvested from PHS was not as good as from RHS, the benefit of application for domestic use is still significant in terms of money saving. The cost of PHS installation can be covered through the saving for the non-potable use, such as garden watering, toilet flushing and car washing. Besides that, the adoption of two-piped system to distribute the harvested rainwater for non-potable use in the residential area will reduce the use of treated water from pipe water and hence, the cost of treatment for potable use can be reduced.

In order to improve the rainwater quality, the harvested rainwater must be treated for further usage, especially for potable water demand. A lot of affordable treatments have been developed and introduced for both RHS and PHS systems, such as first flush water diverter, chlorination, pasteurization and slow sand filtration. For RHS case study in Canada, [21] found that the application of first flush method that cut the first flush of the rain event can significantly reduce the concentrations of polycyclic aromatic hydrocarbons (PAH), suspended solids, organic compound and trace metal. Another study by [56] reported that chlorination method can improve the microbiological quality of harvested rainwater by breaking down the microorganisms, but the reaction between the chlorine and organic matter can form undesired products at the bottom of tanks. Therefore, [18] recommended that better treatment can be achieved by coupling chlorination and membrane filtration. Besides that, the slow sand filtration treatment is also commonly applied in RHS, especially in developed countries, such as Ireland [18], Canada [21] and Australia [17], which involves graded sand layers with continuous water flow through the coarse sand at the top and finer sand at the bottom. Despite disinfection, consumers in Malaysia favored to boil the water as a prevention of bacterial contamination of harvested rainwater and could be considered as drinking water.

For PHS case study in South Africa and United Kingdom, it was stated that harvested rainwater needed a filtration treatment prior ultraviolet (UV) disinfection due to the dependence of dosage on the UV transmittance to ensure the consistency of water quality [66]. On the other hand, for potable water demand, the harvested rainwater of PHS needs chlorination to improve the sanitation systems [25].

3.3. Energy consumption

Energy consumption in RWHS is normally referred to the electricity used for water storage pumping. Theoretically, RWHS consume less energy as compared to conventional system and other alternative water supply systems, such as saltwater (desalination of seawater) and greywater (reuse of water that used for bathing, laundry or washing dishes), depends on site characteristic, system configurations and economic scale [76]. For example, In Jordan, the government revealed that the conventional water supply system consumes 15% of total Jordan electricity to pump and deliver the water, where RHS that does not consume any energy [77]. Although RWHS consume less energy compared to conventional system, the harvested rainwater without treatment can only satisfy non-potable use, as treatment system like membrane filtration consumes more energy.

[78] conducted a case study using Plugrisost programme to analyze the implementation of an RWHS in a single-family house in Aveiro, Portugal. Based on the Plugrisost model, RHS application in a single house scale tends to have lower energy consumption compare to the distribution of the conventional system [78]. However, the condition is different for high rise buildings, where more energy is consumed, with an average of combination between energy production and water distribution network. This has led to more energy being consumed for RHS in developed countries due to limited space areas for development. In Australia, tap water is more important than energy consumption, because lower cost of energy is estimated compared to the higher future prediction of the tap water price [79].

Energy consumption in PHS is based on the elevations and distance [80]. If the PHS area is located at the area with higher elevation, the harvested rainwater can be distributed under gravitational force with little or no pumping is required. However, if the harvested rainwater is distributed to a higher level than the PHS, then a pump (and energy) is needed. Similar to the distance factor, if the PHS is located far from the distributed area, more energy is needed for pumping. Size of PHS is also another factor, where more energy is consumed for larger pond size. A study by [80] reported that the pumping cost increased accordingly with the increase of PHS size due to larger amount of rainwater that is harvested.

4. Benefits and challenges

This section will discuss on the benefit and challenges of RWHS that existed in term of environmental, economic and social aspects.

4.1. Environmental aspects

Heavy rainfall can cause problems to sewer and watercourses, as these are not able to cope with too high peak discharge. RWHS is a stormwater control measure that provides the water supply and stormwater management at the same time. It has the potential to reduce the peak discharge and heavy rainfall as the systems were designed by diverting the precipitation runoff to the area where it can be used or stored. In South Korea, the flood reduction is estimated between 9 to 12% for areas implemented with RWHS, such as Seoul National University (SNU), Korea Institute of Construction Technology (KITC) and Daejeon World Cup Stadium (WCS) [42]. Furthermore, the flood can be reduced by 1% if 10% of the entire city of Seoul is applied with RWHS. In another study, RHS application was found to decrease the runoff by 28% in New York City [28] and 44% in Cape [81]. According to [28], appropriate usage of tank size for RHS could decrease the annual runoff but it could not eliminate it totally. However, [82] reported a contradiction, where RHS can completely eliminate the runoff. This contradiction may be due to dissimilar precipitation in both places, the size of RWHS used or different methodologies of RWHS analysis.

The peak flow rate is the most important parameter to avoid flood risk whereas RWHS application has the potential of reducing the peak flow rate for a great number of events, depending on the tank capacity and rainfall characteristic. A study by [81] showed that RHS can decrease more than 50% of peak flow rate for more than 50% event with recurrence interval (RI) less than 1 week, but the efficiency starts to fall when the RI increases. For events with a return period of 3 months, the peak flow reduction is less than 2% for 17% of events and less than 10% for 58% of events. This is also supported by [83] who conducted a similar study in East of Paris.

For PHS, the site selection with high to moderate runoff was chosen as the most suitable area [84], where it can harvest more rainwater and is able to reduce the flood risk. Average peak flow reduction by PHS was found for all events with a return period of one year or greater than ten years [66]. This is due to PHS design that can significantly reduce peak flow for smaller events as all the flow events were detained with the allowable pond conditions. Besides peak flow reduction, PHS application also assists in adjusting the imbalance of hydrological cycles and groundwater recharges in urban areas as the design allows large amount of rainwater collected.

4.2. Economical Aspect

In some developing countries where the water tariff is high, the RWHS is considered a low-cost system that involved only the cost of storage and treatment, and it behave as free water source [31]. Besides that, RWHS is able to generate large amount of harvested rainwater as the decentralized system, makes it less expensive from the conventional water supply systems. This is supported by [5], who stated that the cost of RHS (0.0007 USD/m^3) is three times cheaper than the conventional water supply system (0.0018 USD/m^3). In addition, the ability of RWHS to fulfill the domestic water demand has reduce the dependency on the conventional water supply system. In turn, it will decrease the water bills up to 50% for every month and save more money [85].

Benefit-Cost Ratio (BCR) is another standard often used to evaluate the economic feasibility of a project. The higher the ratio (more than 1), the more economically feasible the project. BCR compares the benefits of reduced potable water use with costs of implementing and maintaining RWHS. Generally, BCR of RWHS is influenced by the tank size, location and water use but it is impossible to achieve higher ratio if the water price is lower. For instance, a case study in Australia showed that the BCR obtained is too small which is impossible to achieve ratio greater than one with the current water price of 1.43 USD/m^3 [34]. Another study in Korea has reported that the estimation of BCR was less than 0.2 due to conventional water supply system is very inexpensive [42]. Similar situation occurred in Malaysia, where the water tariff is considered lower (0.39 USD/m^3) compared to

neighboring countries, such as Singapore (2.39 USD/m³) and Indonesia (0.51 USD/m³). The cost of RWHS installation is estimated between USD 400 and USD 3000 which is expensive especially for people in low income category [2]. The costly installation of RWHS has caused longer payback time, usually in years and it is uneconomical to implement, as the installation cost far exceeds the benefits of water, energy and carbon saved.

The potential benefits of PHS in irrigation can be measured through increases in yield and cropped area by comparing a situation where there is no pond water available, to a situation with a pond. In China, a case study was conducted to compare the BCR for various size of PHS, including large, medium and small, and the result showed that all sizes of ponds are profit-making with healthy internal rates of return, positive net present values and BCRs larger than 1. For larger ponds, the BCR is still exceeding 1, even with family labor cost included [80]. In another case study in Ethiopia, it was reported that the investment of 180m³ unlined and lined PHS can be paid in less than 3 and 5 year respectively and benefit cost ratio is equal or exceed 1 [24]. Meantime, it was also stated that concrete PHS with 80m³ of capacity could serve similar irrigation demand as unlined PHS with 180m³ capacity, but concrete PHS has caused longer payback period (9 years), as it involved higher investment costs.

PHS application can also increase the farmers' income with supplementary annual harvest and allow annual planting season throughout the dry seasons [86]. For example, farmers in India experienced substantial increase of income from USD 109.97/year to USD 216.36/year [87] and in Bangladesh, the cost of irrigation can save about USD 1,344.26 million [88]. Besides become the farmers income, PHS application assisted the cost benefit during the flood event. By capturing almost all the runoff, the recovery cost due to flood was saved through the minimal infrastructure damage and saved many lives. Currently, due to lesser PHS application, the flood has caused more losses. For instance, in part of north and eastern Malaysia, the flood disaster has caused the severe damage and loss of property which is exceeded USD 300 million [89].

In summary, for RHS application, it is only economical to be implemented in countries with high water tariff as RWHS consumed less energy and it is considered cheaper than the conventional water supply system. However, in countries with low water tariff, the cost of installation has increased the payback period and become less worthy to implement. Unlike RHS, PHS is suitable to be implemented in the countries regardless of high or low water tariff as it gives high benefit return and short payback period, especially the large pond size. However, this estimation is only applicable for PHS that is used for irrigation, and therefore, further BCR study on PHS application for domestic water usage is needed.

4.3. Social aspect

RWHS gives significant benefits not only to economic and environmental aspects, but the social aspect as well. In some regions that are lack of facilities for conventional water treatment, the harvested rainwater is considered safe and clean for health purposes [90]. The sustainable source of harvested rainwater can supplement the drinking water and food security, which helps to decrease the health problem and provide better life quality for those community. For PHS application, it helps improving the agriculture sector, which spontaneously offered a lot of job opportunities for the villagers, increase the household income and provide children with a better chance in education [86].

Even though RWHS provides a lot of benefits to the society, lack of awareness by the users about the RWHS still exist. In Uganda, the RWHS was mismanaged due to insufficient information caused by the poor road problem, shortage of electricity and limited access to internet [10]. Therefore, it has created gap of knowledge among the villagers, especially about the life cycle expenditure and advantages of RWHS. The knowledge gap has caused the people tend to look forward for public support due to their unwillingness to pay for the operating cost. In Malaysia, the acceptance of RWHS is still unsatisfactory, despite various initiatives taken by the government to promote the RWHS. One of the main reasons for poor acceptance is due to low water tariff, where the price is between USD 0.21 and USD 0.70 [2]. In addition, being blessed with abundant of rainfall has caused the public not

to concern about RWHS as water saving device, which is proven by high rate of domestic water consumption (ranging 209 to 228 lcd) compared to WHO recommended target (165 lcd).

Another factor of low RWHS application is lack of interest by the developer due to cost factor and unfamiliarity to the system. For instance, in Malaysia, the cost factor has acted as the main barrier in implementing RWHS, due to lack of support by the developers as well as lack of financial incentives and subsidies by the government. Most of the developers refuse to cover the 1% cost of RWHS installation from the total cost housing development [91]. On the other hand, the unfamiliarity of RWHS among the developers in Spain has caused the misleading information given the buyer about this system, that the RWHS do not give an added value to a new residential building [67].

5. Way forward

Nowadays, Sustainable Development Goals (SDGs) has become a popular concept adapted by most of the countries in tackling climate change and working to preserve the oceans and forests. SGDs concept that was adopted by the United Nation (UN) aimed to improve the people lives and to protect the planet for future generations including of economic development, social inclusion, and sustainable environmental management [92]. With the application of RWHS, SDGs especially SDG 6 that calls for clean water and sanitation for all people can be achieved with the benefits gained from environment, economic and social aspects. Therefore, cooperation and support from various parties / stakeholders is crucial to ensure the successful application of this sustainable system towards the goals of the 2030 New Urban Agenda for the availability and sustainable management of water.

First and foremost, the government need to break down the barrier of RWHS among the society by associating the mass media in promoting and increasing the popularity of RWHS as well as introducing it from the early stage of school subjects [49]. For example, in Malaysia, the RWHS information could be inserted into a subject named Kemahiran Hidup (Living Skills) or Geography in both primary and secondary school [93]. Meantime, in Australia, the school project on RWHS has been started in certain state governments as well as rebate up to USD 2500 was given for the rainwater harvesting tank installation.

Next, in order to further reduce the cost of RWHS installation, the demand from the users need to be increased to encourage the competition among the suppliers. It involves individual initiative to adopt it into their own house especially for the existing residential area. Therefore, in the beginning stage, the government's support by providing subsidies and tax rebates to the public for RWHS implementation is required [93]. Several countries have introduced the subsidies to support the successful of RWHS especially during the initial stages of installation. For example, Australian government provides subsidies to residents who has installed RWHS through Home Water Wise Rebate scheme [94] and the Germany government subsidized 1/3 of total cost installation or up to USD 2170.48 [95]. Besides subsidies, the tax rebate is another economic incentive which is offered to homeowner or public members who decided to engage the RWHS, and it is also given to manufacturers and suppliers of RWHS materials or equipment. This method was successfully implemented in certain regions of India, with rebate of 6 % on property tax by the Indore Municipal Corporation (IMC) [93]. Those incentives and supports from the government will act as the first move to encourage the RWHS implementation among the public.

Meanwhile, the restriction of pipe water usage especially during critical periods will also encourage the application of RWHS. Such policy has been adopted in Australia, where the water usage was restricted for non-potable use, such as watering gardens and washing car at individual property during dry seasons [96]. Another country, Brazil also implemented this method, where the water tariff will be increased to USD 0.079/m^3, if the water usage is higher than 10m^3/month for local water and sewage utility [97]. In this scenario, the two-piped distribution system which divides the water usage into potable and non-potable use under different sources could reduce the dependency on pipe water from conventional water supply. For example, non-potable use can come from RWHS and potable use come from pipe water. This practice is recommended especially for PHS application in newly developed residential area that involve the large community.

From the previous studies, water tariff is one of the major barriers for RWHS application. By increasing the water tariff, it could change the water usage behavior of society and save more water through RWHS application. For instance, studies in Sydney and Spain has stated that the price should increase from USD 1.40/m^3 to USD 1.57/m^3 and from USD 1.52/m^3 up to USD 4.35/m^3 respectively [34] [78]. Another study in South Korea also stated that the current water price should be increase by five times [42] especially in developing countries such as Malaysia.

6. Conclusions

RWHS is one of the alternative water supplies that has been widely introduced and implemented across various countries. There were many studies and research conducted on RWHS, providing a lot of data and information on the design and performance of RWHS, especially on RHS and PHS application. This review study concluded that:

1. Both RHS and PHS used catchment surface (roof top and land surface) and storage system in their system design but RHS needed another component, which is conveyance system. The difference size of storage system between RHS (small) and PHS (big), give good performance on water quantity for PHS but better water quality for RHS. However, both RHS and PHS were contaminated by biological parameter, which made the system only appropriate for non-potable use and need further treatment for potable use. Meanwhile, performance of energy consumption depends on the location of storage system, where RHS on the high-rise building needs PHS at lower level and far from the area of the consumption needs higher energy consumption.

2. Both RHS and PHS provides the environmental benefits by minimizing the flood risk and reducing peak flow, but PHS application gives an added value by recharging into the groundwater. In economic aspect, RHS application only gives economic benefit for countries with high water tariff, while PHS application benefited all, especially in irrigation and providing additional income to the farmers. Other than that, RWHS has significantly contributed to social benefits especially in health, education and income, but it also faced challenges on creating awareness among the users and developers.

3. To date, most of the studies in fulfilling domestic water demand using RWHS was focused on RHS application, as PHS is mostly being used for irrigation purpose. PHS has potential in reducing the dependency on conventional pipe water, as its large pond size gives high benefit return and short payback period. With two-pipe system in place, the concern on the water quality can be reduced, as the harvested rainwater will only be used on non-potable demand. Therefore, the challenges of PHS application at the early stage required the initiatives from the government to support and encourage its implementation especially in the new residential urban area with tropical climate, such as Malaysia.

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