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Review

A Review of Rainwater Harvesting in Malaysia: Prospects and Challenges

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Abstract: The mismatch between freshwater demand and its availability is a major problem that causes global water scarcity. The exploration and utilization of rainwater seem to be viable options for minimizing the aforementioned issue. This manuscript reviews the prospects and challenges of the rainwater harvesting system (RWHS) in Malaysia. Malaysia can be categorized as a country that has high annual rainfall, as well as high domestic water consumption. Thus, Malaysia is well positioned to harvest rainwater for both potable and non-potable uses. Although the RWH guidelines were issued in Malaysia in 1999, the implementation of RWHS as an alternative water resource is still very limited due to its long return on investment and poor public acceptance. Major future challenges on the implementation of RWHS in Malaysia are to achieve competitive cost, the wide application of commercial buildings, a cost effective treatment system, effective policy implementation, the application of green materials, public perception improvement, and reliable first flush technology. Some recommendations such as providing appropriate subsidies and limiting the use of piped water are necessary for implementing RWHS at wider scales.

Keywords: rainwater harvesting; study trend; benefits; subsidies; policies

1. Introduction

In the new global development, freshwater scarcity has become a central issue in sustainable development. It is obvious that this issue is becoming a threat, as well as the largest global risk in terms of its potential impact. The main driving forces for the rising global demand for freshwater are the increasing world population, improving living standards, changing consumption patterns, and the expansion of irrigated agriculture [1–3]. In addition, the mismatch between freshwater demand and availability is the essence of global water scarcity. Therefore, several studies have been carried out to assess global water scarcity in terms of physical, social, and economical aspects [1,4–6].

In order to reduce and minimize water scarcity consequences, the use of rainwater has been widely accepted as a reliable alternative. Studies on the rainwater harvesting system (RWHS), particularly on the techniques and treatment system, have increased significantly in recent years [7–14]. RWHS can be defined as the collection and storage of rainwater for use rather than to waste it as runoff. In general, RWHS techniques can be categorized into two types, namely surface runoff and roof top RWHS. The advantages of RWHS include potable water savings, the mitigation of flooding in urban catchments, and the reduction of nutrient loads to waterways. In addition, RWHS has other advantages in terms of a lower carbon footprint compared to other water supply systems and more efficient energy use because less pumping is required from source to consumer [11,15]. Moreover, RWHS has the potential to simultaneously address water scarcity problem and reduce dependency on domestic water supply [16].

The selected strategies on the benefit of RWHS are listed in Table 1. It is noted that RWHS have many benefits related to the economy, the environment, technology, and society. For economic benefits, annual domestic cost savings of up to $240 per house can be obtained when implementing the system [17]. In addition, RWHS was expected to be more economical for a higher water tariff [18]. In terms of the environmental benefits, a study in South Korea found that RWHS can reduce up to 10% of flood [19]. This is in line with another study that recommends that RWHS is less economical for water supply alone, unless it is also considered as flood control technology [20]. There is also the potential to delay the development of a new storage infrastructure, because RWHS can reduce domestic water demand [21]. For technology and social benefits, RWHS provides as an alternative water resource and reduces water-related health risks [22–24].

It is well established that RWHS is capable of reducing peak water demands on the urban water supply [25]. The implementation of RWHS in several areas in New South Wales, Australia has resulted in considerable savings of water from the main supply, even in relatively low rainfall areas [25]. The benefits of reduced volume and peak demand can be translated in terms of smaller infrastructure size and savings of operation and maintenance costs [26–29]. For instance, in a suburban area of Melbourne, the use of rainwater tanks can reduce up to 18% and 53% of the network pipe sizes and operational costs [27]. Moreover, a considerable reduction in operating costs and greenhouse gas emissions of regional water supply systems can also be obtained by implementing RWHS [25].

Table 1. Selected strategies on the benefit of RWHS.

Categories	Finding	Location	Reference
Economy	RWHS in a dry and highly populated urban area is less attractive under the present low water tariff scenario but it becomes more promising with increasing tariff.	Barcelona, Spain	Farreny et al. [18]
	Annual domestic cost saving up to $240 per year per house.	Seven major cities in Australia including Gold Coast, Brisbane, Melbourne, Sydney, Adelaide, Perth, and Canberra	Tam et al. [17]
	The benefit of RWHS for water supply alone is less economical unless other benefits such as for flood control are considered.	United Kingdom	Fewkes [20]
Environment	RWHS is predicted to reduce flooding by 10%.	Korea	Kim and Yoo [19]
	Prolong the water storage to be used during dry periods.	Abeokuta, Southwestern part of Nigeria	Aladenola and Adeboye [30]
	RWHS is utilised widely in areas with poor water supplies.	North of Carolina, United States	Jones and Hunt [31]
	Reduce dependency on piped water and delay the development of new storage infrastructure.	The Lower Hunter and Central Coast region of New South Wales, Australia	Coombes et al. [21]
	Large scale rainwater tank can reduce peak flow in sewer system.	Belgium	Vaes and Berlamont [32]
	Meet up to 34% of domestic water use and 10% reduction in peak discharge if all houses in the residential area are installed with RWHS.	Malaysia	Shaaban and Appan [33]
Technology and Social	Effective control of stormwater and water conservation, as well as an alternative water resource.	Canada	Farahbakhsh et al. [22]
	Improve household water management in rural area and reduce water-related health risks.	Uganda	Baguma et al. [23]
	Supplement the existing groundwater and surface water resources. RW is cleaner than the existing supply.	Jordan	Abdulla and Al-shareef [24]

Since RWHS could potentially reduce dependency on the domestic water supply, this system has been implemented in various areas such as agricultural [34–36], residential [37–47], and commercial [7,16,48–51], as presented in Table 2. For residential buildings, high percentage reliability above 95% can be achieved by implementing RWHS for several counties such as Australia [52], USA [53], and Iran [54]. When RWHS is implemented for large roof and high water consumption such as commercial buildings, up to 37% reliability can be obtained [51]. For agricultural fields, the implementation of new techniques with rainwater involvement can improve the yields compared to conventional technique [35].

Also, various methods have been implemented to optimize RWHS [12,13,55]. Hudzori [56] proposed a mathematical model for optimizing water storage tank and water utility supply for RWHS using daily rainfall data in Nusajaya, Johor Bahru. According to Chiu et al. [57], optimum tank size and energy consumption are indicators of the reliability of the system and become economically feasible when both energy and water savings are addressed together. In addition, designing RWHS under different climatic regimes in Italy was also conducted [58]. Their study reported that the performance of RWHS can also be analyzed using demand fraction and the modified storage fraction. Various investigations that aim to implement RWHS in UK have also been conducted such as technical framework [59,60] and socio-technical practices [61,62]. Therefore, several innovations of RWHS by implementing gravity or non-gravity have been established in UK [60].

Table 2. Example of implementation of RWHS.

Location	Application of RWH	Findings	Reference
Australia	Residential buildings	Up to 99% reliability can be achieved by implementing RWHS for non-potable use	Rahman et al. [52]
Australia	Residential buildings	RWHS can meet 96% to 99% and 69% to 99% of the water demand in wettest and driest years, respectively.	Hajani and Rahman [63]
New York	Residential buildings	RWHS can meet 7 to 95% of the water demands.	Basinger et al. [53]
Iran	Residential buildings	RWHS reliability ranges from 1.6–58.3%, 11.9–98.9%, and 0.9–31.6% for Mediterranean (rainfall 288 mm/year), humid (rainfall 1355 mm/year), and arid climates (rainfall 150 mm/year), respectively	Rashidi Mehrabadi et al. [54]
Portugal	Commercial buildings	RWHS is very reliable for pavement washing and garden irrigation	Matos et al. [7]
Australia	Commercial buildings	RWHS reliability can reach 37% of the water demands	Cook et al. [51]

To encourage implementation of RWHS, several countries have issued legislations as presented in Table 3. For instance, the Japanese government offers subsidy and low interest loan to premises for RWHS installation [64]. Alternatively, rebates and tax exemptions are also provided to encourage the implementation of RWHS [65,66]. The Spainish and Belgian governments have mandated the implementation of RWHS for new buildings with a certain roof area [65]. The aforementioned facts reveal that the countries have paid attention to water management practices and serious sought to find an alternative water resource.

Table 3. Legislation and incentive to encourage the use of RWHS in the world.

Country	Legislation and Application	Reference
Japan	Subsidy and low interest loan are provided by the government to premises for RWHS installation.	Furumai et al. [64]
Australia	The government offers up to $500 rebates to houses that install a RWHS.	Rahman et al. [67]
Taiwan	A new guideline for RWHS as new water conservation alternative for domestic water use is issued for national buildings.	Cheng et al. [68]
Uganda	The government provides subsidies to RWHS construction materials in rural areas.	Baguma and Loiskandl [69]
Jordan	The government has incorporated RWHS in the water demand management policy.	Abdel Khaleq and Dziegielewski [70]
Spain	The government has made it mandatory for new buildings with a certain garden area to install RWHS.	Domènech and Saurí [65]
Brazil	The government has promoted a programme that aims to install one million cisterns in semi-arid areas.	Domènech and Saurí [65]
Belgium	The government has mandated for new buildings with a roof area greater than 100 m^2 to install RWHS.	Domènech and Saurí [65]
USA (Texas)	The government provides rebates and tax exemptions to foster rainwater use.	Domènech and Saurí [65]
Germany	Premises with RWHS are exempted from stormwater taxes.	Herrmann and Schmida [66]

Malaysia is a tropical country that is relatively rich in water resources with an average annual rainfall of 2400 mm [71]. Although Malaysia has never experienced any serious water crisis in the past few decades, uneven distribution of rainfall over space and time has led to some areas suffering from dry spells, while others have been affected by major flooding. The aforementioned facts revealed that the use of rainwater for alternative water resources and flash flood reduction is crucial and has a high potential.

2. Water Issues in Malaysia

The future rainfall in several states in Malaysia is predicted to decrease due to climate change effects [72]. The predicted change in the rainfall regime would have serious water supply repercussions in highly populated urban areas [73]. In general, annual rainfall map in Malaysia is shown in Figure 1. For comprehensive knowledge, the frequent rain event in Malaysia ranges from 132 to 181 days/year as presented in Table 5. In addition, Figure 2a shows average annual non-revenue water levels over Malaysia from 2010 to 2016 with an average of 36% [74]. For various states in Malaysia, the lowest and highest non-revenue water levels are P. Pinang (19%) and Pahang (50%), respectively.

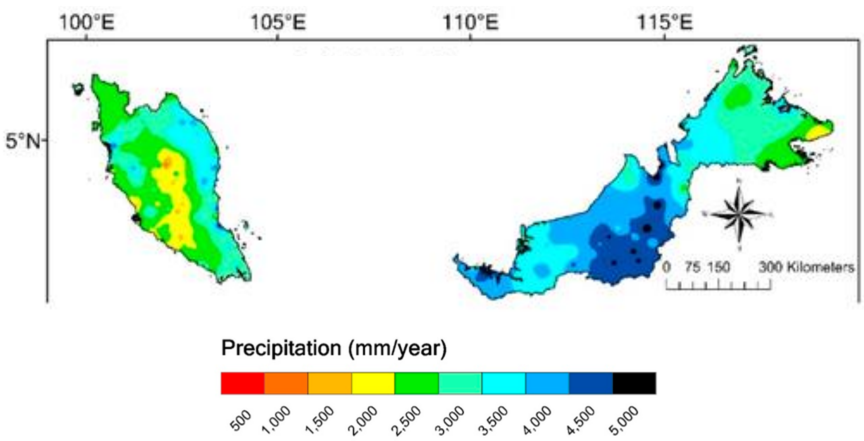

Figure 1. Annual rainfall intensity map over Malaysia [75].

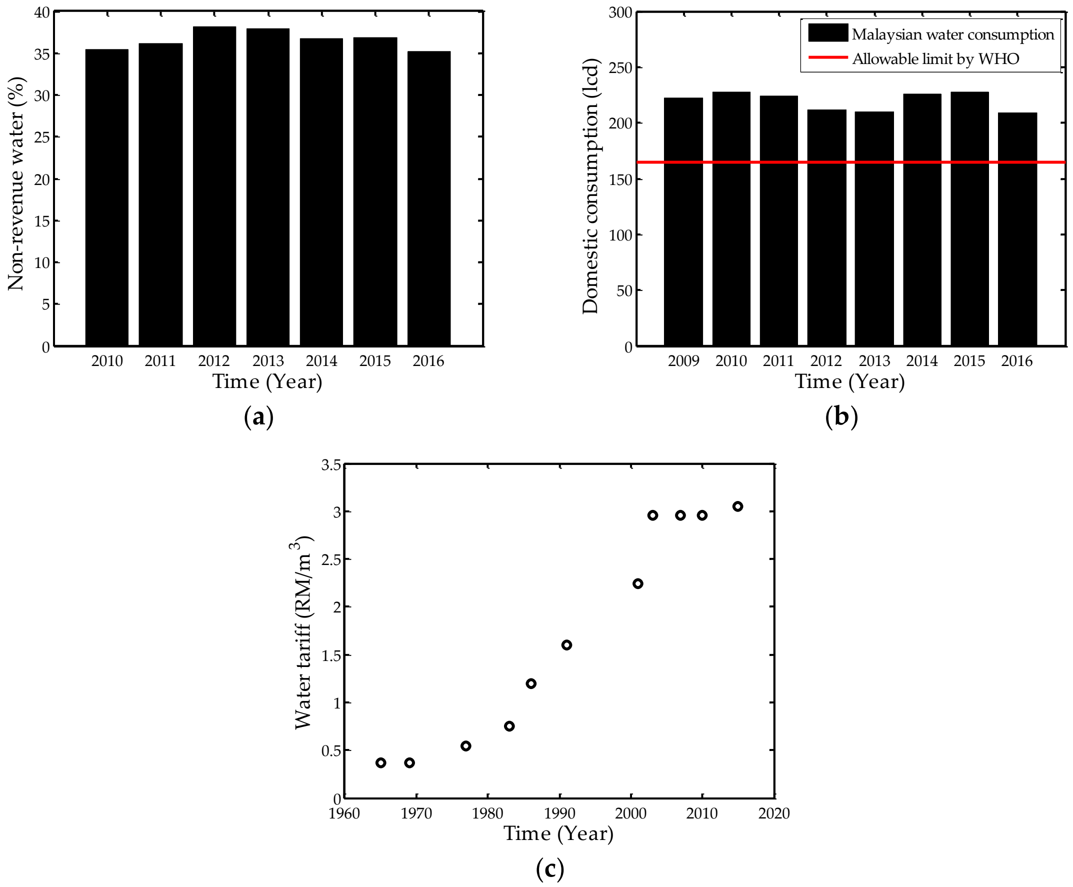

Figure 2. (**a**) Non-revenue water, (**b**) domestic water consumption, and (**c**) water tariff for Johor, Malaysia. RM1 is equal to 0.28USD obtained from an average currency data from 01/2008 to 01/2018.

Moreover, Malaysia can be categorized as one of the countries that has high domestic water consumption, which ranges from 209 to 228 liters per capita per day (lcd) as shown in Figure 2b. The consumption is still above the recommended target by the World Health Organisation (WHO), which is 165 lcd [74]. In this context, Penang records the highest water domestic consumption, while Sabah is the lowest. Moreover, Malaysians use much more water than their neighbors, Singaporeans, which is only 143 lcd in 2017 [76]. Therefore, Malaysia may undergo a water shortage crisis in the foreseeable future if water consumption is not improved.

Although, in general, the water tariff in Malaysia is still low compared developed countries (see Table 4), the tariff shows increasing trend for all states. For instance, in Johor, the commercial water tariff has been increasing from RM0.37/m^3 in 1965 to RM3.0 m^3 in 2015 and is still predicted to increase further as presented in Figure 2c [77]. This situation might become problematic for developing countries including Malaysia, particularly for the poor who have to allocate a greater proportion of their income to getting clean water.

Table 4. Current water tariff in Malaysia [77].

State	Domestic	Non-Domestic
Johor	3.00	3.30
Kedah	1.30	1.80
Kelantan	1.42	1.80
Labuan	2.00	2.28
Melaka	1.45	2.05
N. Sembilan	1.40	2.70
P. Pinang	1.30	1.45
Pahang	0.99	0.99
Perak	1.03	1.40
Perlis	1.10	1.30
Selangor	2.00	2.28
Terengganu	1.00	1.15

The above water tariff is presented in RM/m^3.

Table 5. Mean annual rainfall and number of rain-days for selected towns [78].

Name of Town	Period of Record	Number of Rain-Day/Year
Alor Star	1948–2007	147
Ipoh	1972–2008	181
Klang	1953–2008	132
Kuala Lumpur	1953–2008	177
Seremban	1959–2008	141
Melaka	1954–1998	179
Kluang	1948–2006	163
Johor Bahru	1948–2007	158
Kota Bharu	1981–2008	138
Kuala Terengganu	1954–2008	161
Kuantan	1948–2008	136
Kota Kinabalu	1985–2009	177

The water demand in Malaysia is observed to increase from 10.4 billion m^3/year in 1998 to 12.1 billion m^3/year in 2010 and is projected to increase further to 17.7 billion m^3/year in 2050 [79]. It is well known that 97% of water supply in Malaysia is abstracted from surface water sources, primarily rivers [80]. Malaysia has 189 river basins (89 in Peninsular Malaysia, 78 in Sabah, and 22 in Sarawak). However, in some highly developed and populated areas such as in Selangor, Putrajaya, and Federal Territory of Kuala Lumpur, the river resources have been fully exploited [81]. Therefore, an alternative water resource should be introduced to reduce over dependence on river water and helping the poor to reduce the water bill.

3. Global Perspective of RWHS

RWHS can be defined as direct collection of rainwater from roof and other purpose-built catchments and the collection of sheet runoff from man-made ground or natural surface catchment and rock catchment for potable and non-potable uses. Studies on RWHS have been intensively carried out, since this system has several advantages for the environment and community [82–91]. Over the past four decades, the number of studies related to RWHS has increased exponentially as shown in Figure 3 based on a keyword 'RWHS' in Scopus database. At the time of this research, total publication related to the topic identified via keywords "rainwater harvesting" is 2000.

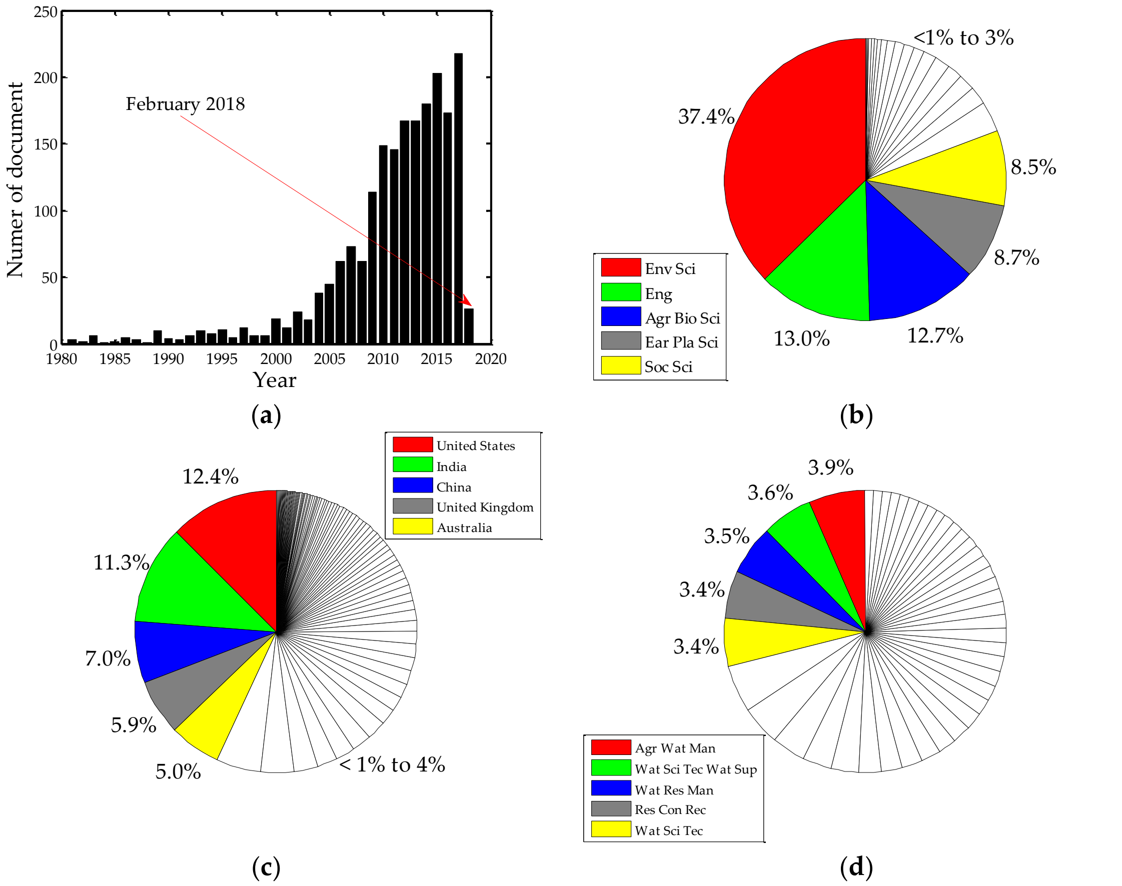

Figure 3. (**a**) Publications from 1966 to May 2017, (**b**) subject area, (**c**) countries publishing RWHS topic, and (**d**) source of title publishing RWHS topic identified via keywords "RWHS" in Scopus database accessed on 9 February 2018 [92].

RWHS provides high quality water, reduces reliance on the piped water, and generally is cost effective. The RWHS can range in size from simple to large scale systems. An approach of RWHS collected from the roof of a building provides the practical and effective utilization of rainwater. RWHS can be applied for both small and large-scale premises, but certain criteria need to be satisfied before implementing the system.

4. RWHS in Malaysia

4.1. Policy

The severe drought in 1998, especially in Klang Valley, has triggered the Malaysian government to embark RWHS. Following this water crisis, the Ministry of Housing and Local Government has promoted houses to install rainwater collector. Therefore, the government has issued a guideline on installing a rainwater collection and utilization system in 1999. Following this, various initiatives in the form of policies and guidelines have been formulated by various agencies (Table 6). This is to facilitate the implementation of RWHS for residential and government buildings.

To support the program, several projects have been carried out by the Malaysian government (see Table 7). In addition, it can be seen from Table 7 that various RWHS projects such as underground and aboveground tanks have been implemented. Most RWHS projects in Malaysia use high-density polyethylene (HDPE) for the aboveground tanks. Total costs to install RWHS range from RM 20,000 to RM 350,000 depending on the size and type of building. The Malaysian government pays attention to RWHS as an alternative resource to reduce over dependence on river and other surface waters.

Table 6. Policies and guidelines related to RWHS under Malaysian government [93].

Guidelines	Department/Agency	Year
Guidelines for installing a Rainwater Collection and Utilization System	Ministry of Housing and Local Government	1999
RWHS: Guidebook on Planning and Design	Department of Irrigation and Drainage Malaysia (DID Malaysia)	2009
Guideline on Eco-Efficiency in Water Infrastructure for public Buildings in Malaysia	National Hydraulic Research Institute of Malaysia	2011
Urban Stormwater Management Manual for Malaysia, MSMA 2nd Edition	DID Malaysia	2012
Panduan Pelaksanaan Inisiatif Pembangunan Kejiranan Hijau—Sistem Pengumpulan dan Penggunaan Semula Air Hujan	Federal Town and Country Planning Department	2012
Garis Panduan Perancangan Kejiranan Hijau	Federal Town and Country Planning Department	2012
Garis Panduan Sistem Pengumpulan dan Penggunaan Air Hujan	Federal Town and Country Planning Department, Ministry of Urban Wellbeing, Housing and Local Government	2013
Urban Stormwater Management—Part 6: RWHS, MS2526-6:2014	Department of Standards Malaysia	2014

Table 7. Selected RWHS implemented by DID Malaysia [94].

Location	Tank Category	Cost (RM)
DID Office, HQ KL	Underground Tank	200,000
DID District Office, Bera, Pahang	Underground Pipe Package	48,000
DID District Office, Raub, Pahang	Underground Pipe Package	185,000
DID District Office, Balik Pulau, P. Pinang	Underground Pipe Package	48,000
DID District Office, Seberang Perai, P. Pinang	Underground Tank	180,000
DID District Office, Langkawi, Kedah	Above ground HDPE Tank	200,000
DID District Office, Pasir Putih, Kelantan	Above ground HDPE Tank	200,000
DID District Office, Kuala Berang, Tere ngganu	Above ground HDPE Tank	200,000
DID District Office, Miri, Sarawak	Underground Pipe Package	145,000
DID Mechanical Office, Ipoh, Perak	Above ground HDPE Tank	200,000
University Tun Hussein Onn Hostel	Underground Tank	350,000
MARDI Office, Cameron Highlands, Pahang	Above ground HDPE Tank	40,000
State Mosque, P. Pinang	Underground Tank	125,000
Bukit Indah Mosque, Ampang, Selangor	Underground Tank	200,000
Building Complex, Tioman, Pahang	Above ground HDPE Tank	200,000
Buffalo Park, Langkawi, Kedah	Above ground HDPE Tank	100,000
Bungalow House, Bangi, Selangor	Underground Pipe Package	20,000
Terrace House, Gombak, Selangor	Above ground HDPE Tank	20,000
National Zoo, Ampang, Selangor	Above ground Concrete Tank & Underground HDPE Tank	400,000

4.2. Study Trend

Since the launching of RWHS program in Malaysia, several studies have been carried out to support this initiative [55,95–101]. Until today, total publication related to the topic identified via keywords "RWHS" is 47 as presented in Table 8 [92]. Universiti Putra Malaysia, Universiti Kebangsaan Malaysia, University of Malaya, Universiti Teknologi MARA, and Universiti Teknologi Malaysia are the top five institutions publishing RWHS topic as listed in Table 9.

Sultana et al. [98] evaluated the effects of green roof on rainwater quality. In general, the quality of roof water is good and requires minimal treatment for dissolved oxygen (DO) and pH. Alternatively, Abdul Ghani et al. [97] analyzed rainfall to determine the potential of RWHS site in Kuantan, Pahang. The highest amount of rainfall was in December and the lowest in February. Moreover, Hamid and Nordin [102] observed the reliability of RWHS installation system at a university hostel in Shah Alam, Malaysia. It was estimated that the installation of RWHS would reduce usage of treated water by about 6500 m^3 per year and save up to RM 10,460 per year.

Hashim et al. [55] proposed a simulation-based program for optimization of large-scale RWHS. Specifically, this study investigated the suitability of RWHS for a community of 200 houses with an average total daily water consumption of 160 m^3. Their study found that the optimal size storage tank for a 20,000 m^2 roof area is 160 m^3 with 60% reliability. In addition, their study also confirmed that a significant water saving of up to 58% can be achieved using their proposed model. The estimated total cost for the system is USD 443,861 and expected life-span of 25 years. Shaheed and Mohtar [101] investigated suitability of the rainwater quality as alternative drinking water source in Selangor, Malaysia. Their study confirmed that the physio-chemical quality parameters such as pH, DO, TSS, COD, and NH_3-N adhered to the drinking water standards permitted by the Malaysian authorities.

The above-mentioned works confirm that there is a need to promote RWHS at the biggest scale. In this context, the National Hydraulic Research Institute of Malaysia (NAHRIM) has collaborated with other government agencies such as DID, Department of Local Government, Universiti Teknologi Malaysia, Universiti Sains Malaysia, and Universiti Malaya to conduct research on RWHS. Presently, NAHRIM pursues research and development (R&D) of RWHS focusing on hydrologic and hydraulic design, system design and performance, installation and operational costs, and water quality aspects.

Table 8. Total publication identified via keywords "rainwater harvesting" in Malaysia [92].

Year	Number of Scientific Paper
2018	3
2017	10
2016	10
2015	7
2014	1
2013	6
2012	3
2011	3
2009	3
1989	1

Table 9. Top five institutions publishing RWHS topic [92].

Institution	Number of Scientific Paper
Universiti Kebangsaan Malaysia	12
Universiti Putra Malaysia	10
University of Malaya	7
Universiti Teknologi MARA	5
Universiti Teknologi Malaysia	5

4.3. Benefit of RWHS

In general, the benefit of RWHS can be divided into two categories, namely, environmental and economic [31]. For environmental benefit, it can be used as alternative water supply to supplement piped water. When used at large scale, RWHS can help to reduce flash flood in urban area and minimize soil erosion, as well as to prevent pollutant from entering water bodies [52].

Specifically, the economic benefit of RWHS has been examined by several researchers as listed in Table 10. Since RWHS is very useful for non-potable water use, it has the potential to reduce bills. Financial viability analysis of the RWHS was assessed for single and multi-family buildings [65]. Their study found that the payback period of the RWHS investment was between 33 and 43 years, and 61 years for a 20 m^3 tank for single and multi-family buildings, respectively. Rashidi Mehrabadi et al. [54] found that it was possible to supply about 75% of non-potable water demand by storing rainwater from larger roof areas in Iran. Since the benefit of RWHS is highly dependent on water usage, system design, rainfall, and other uncertainty variables, its evaluation of long-term performance is needed to better understand the effects of each variable on its benefits. This is very useful as a basis for designing the future RWHS.

Table 10. The economic feasibility of RWHS.

Location (Average Rain, mm/Year)	Approach of the Research	*r* (%)	*t* (Years)	Finding	Reference
Melbourne (650)	Water balance model for the performance analysis and design of rainwater tanks	-	15 to 21	The construction cost can be recovered within 15 to 21 years depending on the considered variables.	Imteaz et al. [103]
West Yorkshire, UK (∼700)	Life cycle costs analysis (LCCA) of RWH	3.5 to 15	-	The domestic RWHS generally resulted in financial losses approximately equal to their capital costs.	Roebuck et al. [104]
7 cities in Australia (520 to 1597)	Costs of RWH compared to other water supply alternatives	3	6	Implementation of RWHS is an economical option for households compared to others.	Tam et al. [17]
4 cities in Australia (800 to 1600)	Feasibility of RWH in high-rise buildings (payback period)	6.5	8 to 23	City having the highest rainfall provides the shortest payback period in implementing RWHS.	Zhang et al. [105]
Five towns in Brazil (1483 to 2002)	Investment feasibility analysis of RWHS	-	1 to 30	The higher rainwater demand provides more economic feasibility.	Ghisi and Schondermark [106]
Three towns in Melbourne (454 to 1054)	Investment evaluation of RWHS	5 to 10	30 to 46	Payback period is comparatively low for a large tank.	Khastagir and Jayasuriya [107]
A commercial building in Portugal	Economic Assessment of the RWH	5 and 10	2 to 6	The lower discount rate offers the reduction of the payback periods.	Matos et al. [108]
Sydney metropolitan area (675 to 1160)		2.4	8 to 90	Payback periods from 20 to 90 years can be achieved without government rebate. However, the payback periods can be brought down to 8 years when a government rebate is implemented.	Imteaz and Moniruzzaman [109]

r = discount rate and *t* = payback period.

4.4. RWHS Type

In Malaysia, several types of RWHS have been implemented, namely, backyard system, frontage system, and underground system as shown in Figure 4 [110]. Backyard and frontage systems are also established as 'collection systems only', because they have no distribution system. Backyard system is the most popular, because it is cheap and easy to install compared to other systems that require plumbing system. In this system, there are two approaches to locate the storage tank, either on the ground or elevated. Ground tank is widely-established for RWHS development in various countries such as Brazil [111], Australia [63], and Portugal [112], and continents such as Africa [113], while the elevated tank commonly consists of three levels of tank, namely, top, middle, and lower levels. The top-level tank is usually employed for water supply, while the middle and lower level tanks are used for storing the collected rainwater. For this system, metal and polyethylene tanks are normally used for elevated and ground tank, respectively.

For the frontage system, it adopts the same installation concept with backyard system. A modification is usually done by replacing the polyethylene tank using the reinforced concrete tank to facilitate the maintenance work. It is known that the concrete tank is more durable compared to polyethylene tank; thus, it makes it more economical over the long-term [110]. It is also noted that the use of concrete tank is relatively cheaper (up to 38% compared to polyethylene tanks [114]). As for the underground system, the cost, which includes a pump, was about RM1700 for small scale systems such as home consumption [110].

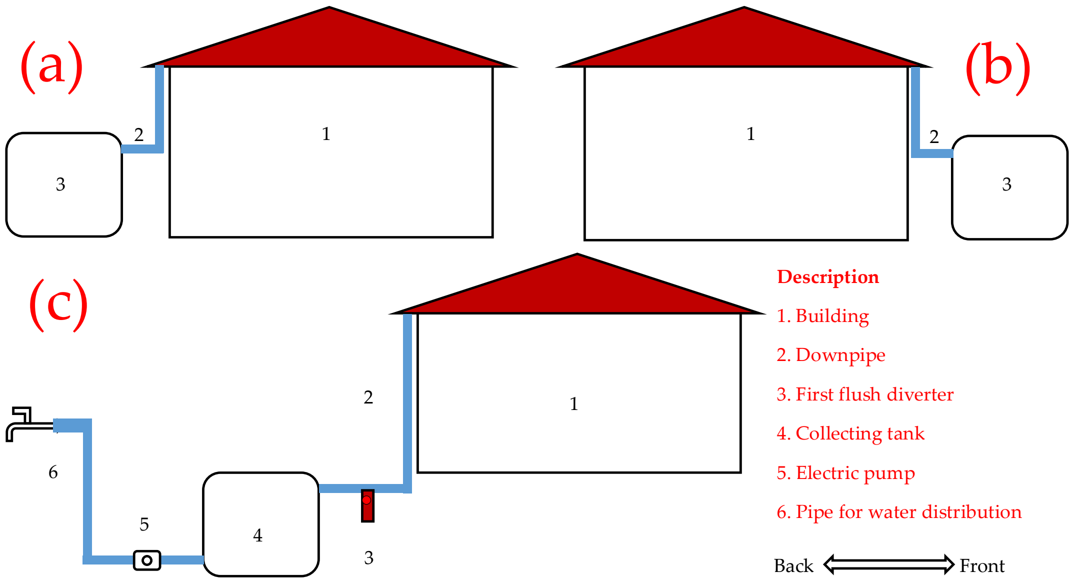

Figure 4. Typical RWHS designs of (**a**) backyard system, (**b**) frontage system, and (**c**) underground system implemented in Malaysia.

4.5. RWHS Software

Since a proper design of RWHS involves a lot of data and analysis, it is useful to use software to expedite the process. Therefore, several computer-based models have been developed and implemented such as the SimTanka2, Warwick calculator, and the Jomo Kenyatta University of Agriculture and Technology's RWHS (JKUAT-RWH) calculator [115]. The SimTanka2 and Warwick calculator are developed to evaluate the optimal tank size of RWHS, whereas JKUAT-RWH calculator is used to estimate the reliability of the system by performing a long-term time series of daily rainfall. Alternatively, Yield After Spillage (YAS) software was designed to estimate the actual rainwater availability and storage conditions [116].

In Malaysia, the software development has been tackled by NAHRIM. Tanki Nahrim is a famous software for calculating the aforementioned analysis [117]. Hamid and Nordin [102] confirmed that software is reliable for evaluating the reliability of a RWHS in a university hostel in Shah Alam, Malaysia. This software was also used to estimate an optimum tank size of the RWHS in another nearby college [118]. However, this software has limitations such as the absence of an economic evaluation [55]. Therefore, a more complete RWHS software that integrates the physical design and economic benefits is crucially needed. This is highly beneficial for providing comprehensive knowledge and convenience to public in order to encourage the implementation of RWHS.

5. Future Challenges

5.1. Cost

The cost is still a problematic issue when applying RWHS for several areas. Initial cost and maintenance are still debatable with regards to how this system can be affordable for all societies, especially for people in the low income category. This limitation is associated with national income and the low awareness of the community. Although water tariff in Malaysia is deemed as one of the lowest compared to neighboring countries such as Singapore (2.39 USD/m^3) and Indonesia (0.51 USD/m^3), the cost to install the RWHS is estimated between USD 400 and USD 3000 [93].

In order to maximize the benefits, an optimum RWHS design is highly crucial. In addition, the material selection can also reduce the initial cost. Designing RWHS using gravity has the potential to reduce the operation and maintenance cost compared to that system with pumping operation.

Moreover, the government may provide subsidies to encourage the public to install the system. Also, training and awareness campaigns are highly beneficial for enhancing the interest of the community.

5.2. Application

Currently, the application of RWHS in Malaysia is still limited to government buildings. The exploration of other potential buildings such as commercial buildings is interesting, since they usually has larger rooftop catchment area. For instance, total catchment area of 10,000 m^2 can provide a potential rainwater collection of 23,000 m^3 annually. Since rainwater quality is almost free from major contaminant [119], only minimum treatment is needed if it is to be used for domestic or cooling purposes.

Therefore, the savings from implementing RWHS in commercial buildings are more rewarding compared to small installations in houses, because the commercial water tariff is higher, and the water consumption is bigger. The benefits of installing RWHS are more attractive when it is implemented early during the design and construction phase as opposed to during the retrofitting of the existing building. Therefore, implementation of RWHS in the foreseeable future should be more intensively applied for large buildings.

5.3. Treatment System

Most of the existing RWHS is for non-potable uses, in which the water is used directly from the collection tank. Although rainwater in Malaysia is relatively clean from major contaminants, minimum treatment is still needed before it can be utilized for potable uses. Table 11 lists the roof rainwater quality in Malaysia [120]. It is obvious that some parameters such as turbidity, lead, fecal coliforms, and total coliforms are present above limit regulated by World Health Organization (WHO). The aforementioned facts reveal that a simple treatment still needs to be done before the rainwater can be widely used for potable uses.

Table 11. Summary of roof rainwater quality for different roof types in Malaysia.

Parameter	Galvanized Iron Roof	Concrete Roof	WHO Standardization
pH	6.6 to 6.4	6.8 to 6.9	6.5 to 8.5
Turbidity (NTU)	10 to 22	25 to 25	5
Total solids (mg/L)	64 to 119	116 to 204	-
Suspended solid (mg/L)	52 to 91	95 to 153	-
Dissolved solid (mg/L)	13 to 28	23 to 47	-
Zinc (mg/L)	2.94 to 4.97	0.05 to 1.93	5
Lead (mg/L)	1.45 to 2.54	1.02 to 2.71	0.05
Fecal coliforms (MPN/100 Ml)	0 to 8	0 to 13	0
Total coliforms (MPN/100 mL)	25 to 63	41 to 75	0

Therefore, it is worthwhile incorporating a simple treatment system in order to maximize the economic benefit of RWHS. Although many methods such as disinfection [121], slow sand filtration [9], membrane filtration [122], pasteurization [9], ozonation [123], and adsorption [124,125] are possible, their cost and suitability are important to be consider. In order to maximize the investment benefits, a clear goal of constructing RWHS should be considered prior to installation.

The selection of rainwater treatment method has implications for the installation and maintenance costs. For instance, non-potable uses of harvested rainwater such as toilet flushing, landscape irrigation, and car washing do not require treatment. Conversely, the use of harvested rainwater for potable uses such as drinking, cooking, shower, and cloth washing needs a cost-effective treatment method. Treatment is also necessary when the harvested rainwater is used for chiller system. Therefore, it is crucial to provide a cheap treatment method to maximize its economic benefit. In addition, a simple treatment system with less maintenance has additional benefits for installation in rural areas. In this regard, filtration with pH adjustment (to ±pH 7) would be sufficient for treating rainwater for chiller system, whereas for domestic uses, additional treatment trough disinfection is necessary.

5.4. Rainfall Characteristics

The success of RWHS is greatly dependent on the quantity and temporal pattern of the rainfall. It was estimated that the percentage of reliability of RWHS for toilet flushing, laundry, and irrigation use increased from 40% to 71% for study locations having an average annual rainfall ranging from 743 mm to 1325 mm in Australia [63]. As listed in Table 5, average annual rainfall in Malaysia varies according to the region. For instance, Seremban and Kuantan have the lowest and the largest annual rainfall, which are 1901 mm and 2881 mm, respectively.

To maximize its benefit, the development of RHWS in Malaysia should consider their rainfall quantity. For a similar roof area and water consumption rate, the higher rainfall depth would be more reliable. Moreover, being located in the humid tropic region, the number of rainy days in Malaysia is high (138 days to 181 days/year). Thus, the use of RWHS should be maximized in order to have the biggest water savings in the reservoir that is to be used during dry period. Considering the spatial variation of rainfall in Malaysia, it is crucial to assess RWHS potential for various rainfall regions.

5.5. Policy

Although the Malaysian government has launched RWHS policy, the implementation has been mostly confined to public buildings, and bungalows and semi-detached houses. The DID Malaysia has been promoting RWHS projects for various types of buildings as listed in Table 7. For each project, either above or underground RWHS tanks were installed. Most of the projects installed HDPE tank except for National Zoo project, which used concrete tank. Depending on the tank size and category, the installation cost ranges from RM 20,000 to RM 400,000.

For future, the RWHS policy should be extended to all buildings with large roof area such as commercial buildings, which are expected to have a larger economic benefit. Unfortunately, the existing policy is still quite loose [93]. There is no mention of the minimum requirement of tank size in relation to roof area. In addition, commercial buildings are still not subjected to this policy. Therefore, a comprehensive study considering an optimum tank size according to the various roof sizes and climatic conditions in Malaysia should be carried out for foreseeable future as a scientific judgement before issuing a legal policy.

5.6. Material

Rainwater is relatively clean but can be contaminated by the roof materials and deposition on the roof surfaces. In older systems, the commonly used roof materials were steel, copper, aluminium, zinc, or tin. Overtime, the roof materials become rusty and were subjected to leaching by rainwater, which is normally quite acidic (about 5.6) [126]. Thus, it became a source of contaminant in the collected rainwater. In addition, application of paint, tar, glue, sealant, and other protective materials in order to lengthen the roof life span may contribute additional forms of contaminant. Moreover, there are various types of tanks depending on the materials being used such as polyethylene, concrete, galvanized steel, fiberglass, and stainless steel, which tend to rust overtime and could release certain chemicals.

These shortcomings could be overcome by introducing more inert and environmentally friendly materials. For this purpose, natural resources such as rattan, bamboo, and oil palm in the form of fibers or particles can be used as composite materials. Natural materials have been proven to have physical and mechanical properties that are comparable to synthetic materials [127]. Therefore, a comprehensive study by applying natural materials is needed crucially in Malaysia. This knowledge is useful to inform the public that better collected rainwater quality can be obtained using inert and environmentally friendly materials.

5.7. Public Perception

Despite various initiatives by the government to promote RWHS, acceptance among Malaysians is still unsatisfactory. One of the main reasons for the poor acceptance is because of low water tariff.

At the moment, Malaysians are paying between RM 0.96 and RM 3.05 depending on the water supply service provider [77]. In addition, the average water tariff in Malaysia is among the lowest in the world (0.20 USD/m^3) compared to neighboring country of Singapore (2.39 USD/m^3) and developed countries such as Tokyo (2.0 USD/m^3), Dubai (2.4 USD/m^3), New York (3.1 USD/m^3), Amsterdam (5.2 USD/m^3), and Copenhagen (7.3 USD/m^3) [128].

Malaysia is also blessed with abundant rainfall with rare occurrences of significant drought. This makes the general public feel that there is no necessity to explore other alternative water resources. It is evident from the high rate of domestic water consumption, ranging from 209 to 228 lcd as depicted in Figure 2b compared to best practice of 165 lcd as benchmarked by WHO [74]. Finally, the public is inadequately educated on the importance of rainwater utilization within the context of water demand management. Both strategies in terms of penalty and incentive are crucial for ensuring fuller implementation of rainwater harvesting at residential, commercial, and industrial premises. For instance, Singapore imposes penalty in the form of much higher tariff when a factory exceeds certain limit of water usage from public supply [129]. On the other hand, Malaysian government can offer incentive by providing rebate to premises owner who installs RWHS. In addition, a proper awareness program is necessary to educate the public on how RWHS can be implemented to reduce the dependency on domestic water supply.

5.8. First Flush Technology

One of challenges in using rainwater is to minimize pollution associated with the first flush. The source of contamination may come from leach out of roof materials, dry deposition, and bird droppings. Traditionally, this can be carried out by manually diverting the first flush from entering into the collection tank. However, this requires the personnel to be on standby. Figure 5 shows typical design of first flush device of RWHS. The existing flush systems still have weaknesses, because the first flush collector has to be emptied manually. In view of the frequent rain event in Malaysia ranging from 132 to 181 days/year as presented in Table 5, this manual removal is not practical, and the collected rainwater is exposed to contamination when the first flush collector is not emptied prior to the next storm event. Therefore, it is possible to automize the first flush by using floating system or mechanical devices.

In Malaysia, the rainfall duration is usually between 0.5 h to 3 h with averages dry period between rainfall ranging from 2.0 to 2.8 days [130]. However, rainfall duration during monsoon period (November to early January) in the east coast region of Peninsular Malaysia may prolong to several days. Automatic emptying of first flush collector is recommended when labor and investment costs are not an issue and high quality roof water is required. Nevertheless, manual emptying is more practical for small scale RWHS in order to minimize the investment cost. In this case, it is necessary to educate the public on the need to consistently empty the first flush collector to avoid possible contamination.

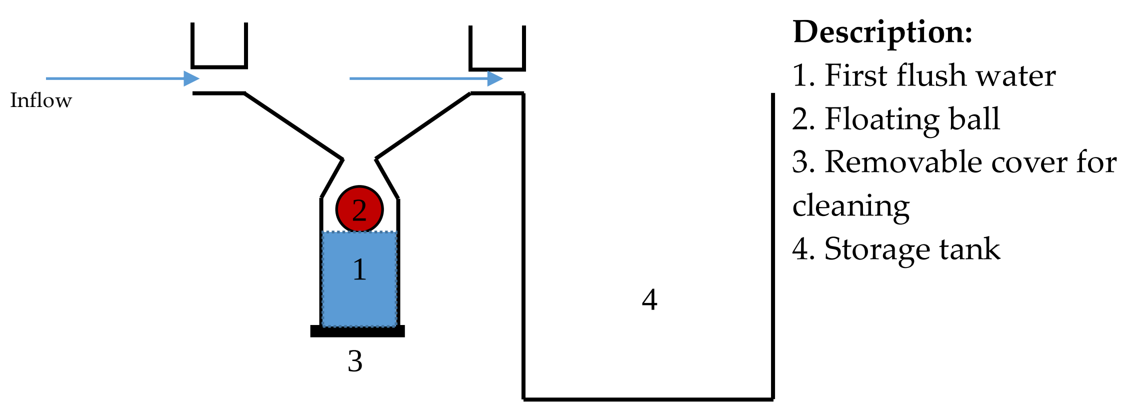

Figure 5. Typical first flush design of RWHS [78].

6. Recommendations to Encourage RWHS in Malaysia

6.1. Subsidies

It is noticed that rainwater harvesting scheme is less attractive in many developing countries. This is because of the high installation and maintenance cost, as well as low water tariff, which result in a long payback period. On the other hand, the success of RWHS in developed countries is contributed to by the support from the government, especially during the initial stages of implementation.

Several countries have introduced subsidies for the premise owner who installed RWHS. For instance in Spain, there are subsidies of up to €1200 for each house owner who has installed RWHS on their own initiative [65]. Australian government has also launched the Home Water Wise Rebate scheme, which provides subsidies to residents who have implemented RWHS for non-potable domestics uses [131]. In Germany, the government supported the installation of RWHS in new or existing households by subsidizing 1/3 of the total costs or up to €2000 [132]. Other countries such as Japan, Uganda, USA, and Germany have also paid attention to encourage RWHS implementation by providing subsidy and low interest, subsidy for construction materials, rebates and tax exemptions, and exemptions from stormwater taxes, respectively. Therefore, similar subsidy scheme can be adopted to boost the implementation of RWHS in Malaysia.

6.2. Regulate Piped Water Use

Another instrument that could be adopted by the Malaysian government to encourage RWHS is by restricting the use of piped water, especially during critical periods. Such measure has been implemented in Australia by restricting the use of water for non-essential purposes such as watering lawns and washing cars at individual premises for certain states particularly during drought seasons [133]. In Singapore, an additional fee of 3.69 S$/m^3, which is increased more than the normal tariff (2.74 S$/m^3), is collected when the amount of water used exceeds 40 m^3 [134]. Similarly, the local water and sewage utility in Brazil imposes a much higher tariff (5.66 R$/m^3) when the consumption is higher than 10 m^3/month compared to the normal rate (3.43 R$/m^3) [135].

Malaysia could emulate such strategy by first educating the public using formal and informal platforms, especially among school children. This should be strengthened by regulations and guidelines. The benefit could be highlighted by providing appropriate tools such as rainwater harvesting software, which includes system design and economic assessment. Moreover, the present water tariff structures in Malaysia seem to be less effective at encouraging the public to save water. A higher water tariff that could change water use behavior might be necessary. Alternatively, more stringent regulation could be introduced for non-essential purposes, particularly for states that experience long dry period and have limited water resources.

7. Conclusions

This paper evaluated the progress of rainwater harvesting implementation globally with a focus on making possible improvements in Malaysia. The implementation of RWHS in Malaysia is very timely because of several water issues such as increasing water demand, high rainfall, and over-dependent on surface water. It is proven that RWHS could offer various socio-economic and environmental benefits. The benefits are bill saving, flash flood reduction, and delaying the need for constructing new water supply infrastructure. Malaysian government has long implemented RWHS, especially in government and public buildings. However, overall the success is still inadequate mainly due to the relatively high investment, low water tariff, lack of incentive from the authorities, low public awareness, and poor enforcement. RWHS is more profitable when implemented on a large scale such as in commercial buildings compared to small scale systems in a residential area. This is because of the large roof area that provides enough volume for high consumption in addition to a higher water tariff compared to a domestic tariff. Several improvements on policy implementation are necessary in order to gain wider acceptance of RWHS, which includes providing an appropriate incentive and regulating the excessive use of piped water.

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