PAPER • OPEN ACCESS

Rainwater Harvesting System (RWHS) for buildings: A mini review on guidelines and potential as alternative water supply in Malaysia

To cite this article: Siti Fairuz Juiani *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1238** 012001

IOP Conf. Series: Earth and Environmental Science 1238 (2023) 012001 doi:10.1088/1755-1315/1238/1/012001

Rainwater Harvesting System (RWHS) for buildings: A mini review on guidelines and potential as alternative water supply in Malaysia

Siti Fairuz Juiani[1], Chun Kiat Chang [1], Choe Peng Leo[2], Hui Weng Goh[1], Wei Lun Ang[3], Rania Fayiz Aburamadan[4]

[1] River Engineering and Urban Drainage Research Centre (REDAC), Engineering Campus, Universiti Sains Malaysia,14300 Nibong Tebal, Pulau Pinang, Malaysia
[2] School of Chemical Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[3] Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia.
[4] The Department of Architecture, Applied Science Private University, Al Arab St. 21, Amman, 11931, Jordan

redac10@usm.my

Abstract. Malaysia receives an abundance of rain annually (≈ 2400mm/year). The country, however, is not excused from water crises such as floods and water shortages. According to the National Water Services Commission (SPAN) data, Malaysia water consumption in year 2021 is 201 LCD and may encounter a water shortage crisis if the situation is not improved in the future. Rainwater harvesting (RWHS) has great potential in tackling water shortages. It can also combat water scarcity holistically and reduce dependency on treated water from dam reservoirs. RWHS is a sustainable alternative to tackle water crises with minimal environmental impact. Currently RWHS is used for non-potable purposes like cleaning, toilet flushing, and irrigation. Due to the nature of the catchment area, there are several ways in which contaminants can enter the rainwater system and compromise the water quality. Elements such as topography, weather, and pollution sources, have a direct impact on the quality of rainwater that is collected and stored. In addition to the non-potable uses, RWH has been used for potable water in countries such as Australia and Bangladesh, but the total number of uses is still very small. For potable use, regular monitoring is required because it poses a health risk due to the presence of chemical, physical, and microbiological contaminants. If the water quality parameters meet the acceptable levels of water supply, harvested rainwater could be used for drinking purposes in many countries in the future. To ensure consistently good water quality, it is essential to establish standard operating procedures and maintenance schedules based on water safety plan approaches for both household and institutional users. This paper aims to review existing management guidelines and explore potential technologies for rainwater harvesting in buildings across Malaysia.

1. Introduction

Climate change is also having a significant impact on Malaysia. Extreme climate events such as droughts, floods, heavy rainfall, rising oceans and hotter temperatures are expected to affect the environment and human society. Although Malaysia receives abundant rainfall annually (≈ 2400 mm/year), it is no exception to facing water crises such as flooding and water scarcity. Previous study on the evaluation of changes in precipitation extremes over the Kelantan River Basin, Northeast Malaysia, from 1985 to 2015, where most extreme precipitation events showed a significant trend [1]. An evaluation of the average annual maximum temperature in Penang from 1985 to 2020 was studied, where extreme drought events were recorded during El Niño years (e.g., 1988–1989, 1997–1998, 2010–2011 and 2014–2016), which is associated with very low precipitation and high temperature conditions [2]. Strong El Niño events in 1997–1998 and 2015–2016 have resulted in prolonged droughts and leading to a water crisis in many regions of Malaysia, including Penang.

Rainwater harvesting systems (RWHS) are one of the alternative sources to address the challenge of the water crisis with the least impact on the environment. The concept of RWHS is to collect and store rainwater for use instead of allowing it to run off. The advantages of using RWHS include solving water shortage issues during droughts or polluted surface water for water intake and reducing the dependency on conventional water supply [3], [4]. RWHS expected to reduce flooding and land erosion caused by runoff from impervious covers such as roofs and pavements [5]. Recently, the focus of RWHS has been on non-potable uses. However, based on past research, RWHS can be used as a source of drinking water if proper treatment procedures are followed. Therefore, the aims of this review paper are: (1) to review the guidelines of RWHS in Malaysia and (2) to evaluate rainwater harvesting technology as an alternative water supply.

2. Guidelines Rainwater Harvesting in Malaysia

2.1. Principle and Design

Table 1 shows the list of guidelines that have been established for RWHS in Malaysia. The promotion of RWHS in Malaysia started in 1999 with the introduction of the first guidelines, "Guidelines for Installing a Rainwater Collection and Utilization System", which was introduced by the Ministry of Housing and Local Government after the 1998 drought. The manual is intended as a reference for users wishing to install a rainwater collection system and does not address cost and implementation issues, which poses problems for new users as RWHS has been relatively new in Malaysia since 1999. The guidelines aim to reduce reliance on treated water and provide a back-up supply during periods of water shortage. According to Mohd-Shawahid et al. [6], the successful development of rainwater harvesting in Malaysia occurred on 27 March 2006 when the government announced that rainwater harvesting was mandatory, although it was only used for large buildings such as bungalows, factories, and schools. This is the most encouraging development for the success of rainwater harvesting in Malaysia and will be a positive start for sustainable development in the country.

In the same year, the Ministry of Energy, Water and Communications introduced two new water laws, namely the Water Services Commission Act 2006 and the Water Services Industry Act 2006, through which the Ministry promotes rainwater harvesting technology in Malaysia. The Ministry prepared a Cabinet Paper to the National Water Resources Council to encourage federal and state government buildings to install rainwater collection and utilisation systems after the introduction of five-year guidelines. However, the implementation of rainwater harvesting in government buildings is not mandatory and is only encouraged by the Council. The Department of Irrigation and Drainage (DID) Malaysia and the Ministry of Energy, Water and Communications (KTAK) are the two government agencies that have implemented the RWHS during the early adoption of this system for government buildings. Subsequently, many initiatives have been formulated by various agencies such as the Department of Irrigation and Drainage (DID), Kuala Lumpur City Hall (DBKL) and the Public Work Department (PWD) to facilitate the implementation of RWHS. The existing guidelines from 1999 to date have the same purpose which is to focus on the principle, planning, design, and installation. Previous researchers have pointed out the lack of information on the existing guidelines, such as a manual for minimum or optimum tank size and technical specification of installation method [7], [8], [9]. The different guidelines of other countries can also be shown in Table 2.

Table 1. RWHS related guidelines Malaysia.

No	Guidelines	Department/Agency	Year
1	Guidelines for Installing a Rainwater Collection and Utilization System	Ministry of Housing and Local Government	1999
2	Rainwater Harvesting: Guidebook on Planning and Design	Department of Irrigation and Drainage Malaysia	2009
3	Guideline on Eco-Efficiency in Water Infrastructure for public Buildings in Malaysia	National Water Research Institute of Malaysia	2011
4	Urban Stormwater Management Manual for Malaysia, MSMA 2nd Edition	Department of Irrigation and Drainage Malaysia	2012
5	Green Neighborhood Development Initiative Implementation Guide – Rainwater Collection and Reuse System	Federal Town and Country Planning Department	2012
6	Green Neighborhood Planning Guidelines	Federal Town and Country Planning Department	2012
7	Rainwater Collection and Use System Guidelines	Federal Town and Country Planning Department, Ministry of Urban Wellbeing, Housing and Local Government	2013
8	Urban Stormwater Management – Part 6: Rainwater Harvesting, MS2526-6:2014	Department of Standards Malaysia	2014
9	Rainwater Harvesting System Design	Public Work Department	
10	DBKL Rainwater Harvesting Guidelines	DBKL	2014
11	NAHRIM Technical Guide No.2 - The Design Guide for Rainwater Harvesting Systems	National Water Research Institute of Malaysia	2015

Table 2. International RWHS related guidelines in different countries.

Country	Guidelines	Summary
USA	The Texas Manual on Rainwater Harvesting (2005)	Aim to ensure the quality and safety of rainwater for various uses by preventing debris entry, removing sediment, treating microbiological contaminants, and improving taste.
	Rainwater Harvesting Potential and Guideline for Texas (2006)	Aim to maintain the quality of stored rainwater, ensuring it is free from contaminants and safe for various uses.
	International Residential Code: Potable Rainwater Collection & Distribution System, Arizona	Aim to ensure the quality and safety of rainwater for various uses by preventing debris entry, removing sediment, treating microbiological contaminants, and improving taste.
Australia	Rainwater Treatment Guide	Focus on the appropriate choice of filtration method depends on the specific contaminants present and the desired level of water quality.

Table 2. International RWHS related guidelines in different countries **(***Cont)*.

Australia	Guidance on Use of Rainwater Tanks	Focus on maintaining water quality in rainwater using effective disinfection by chlorine or UV light, boiling for microbial elimination, and proactive maintenance to prevent contamination.
Jordan	Greywater Treatment and Reuse, And Rainwater Harvesting and Collection at Home Guideline	Effective water treatment involves using chlorine for pathogen elimination, filtration through sand filters or membranes, and careful maintenance of the collection tank and catchment areas to ensure water quality.
Lebanon	National Guideline for Rainwater Harvesting System	Involves multiple stages, including straining, settling, chlorination, filtration, and sterilization. The treated water is then stored in appropriate tanks for domestic or potable use. Regular testing is necessary to ensure the water remains free from contamination.

2.2. Water Safety

Despite the benefits, current guidelines on RWHS still lack adequate guidelines on water safety and rainwater quality when using rainwater harvesting for both drinking and non-potable uses. Ahmed [10] also agreed that RWHS is not widely used for potable and non-potable uses due to lack of risk information and the presence of chemical and microbiological contaminants. The Water Safety Plan (WSP) Handbook for Rural Water Supply Systems [11] is a guideline on the safety of water supply that was formulated by the Ministry of Health, Malaysia in 2011 due to the high incidence of waterborne and excreta-related diseases reported in Malaysia in the 1960s, where most of the rural population used unsanitary water supply. One of the systems installed in rural areas is the rainwater collection system. The WSP is a guide to ensuring the safety of drinking water supplies using a comprehensive risk assessment and risk management approach, covering all stages of the water supply from catchment to consumer. Based on the WSP, the level of risk can be calculated, and control measures proposed. The guidelines also list the treatment method for the rainwater catchment system, but there is no additional information such as a specification for the treatment method. If there is no proper treatment towards water collected from the roof especially for drinking purpose, the potential disease risk for people consuming the water. The significant issue related to water collected for roof is the health related to heavy metals and microbial pathogens [10], [12], [13], [14]. A microbial pathogen in rainwater could be present in the faeces of birds, insects and animals that have access to the roof.

In the future, new guidelines for rainwater harvesting should be considered for the water quality of rainwater, even for potable use. Two (2) main parameters that many researchers usually discuss regarding rainwater quality are chemical contaminants and microbial pathogens, which should be considered for potable use. The specifications of the treatment technology for potable purposes should be further addressed in the guidelines as Malaysia should be prepared to implement rainwater harvesting as an alternative water supply for potable purposes in the future, given the current situation of global water scarcity issues. Therefore,-ensuring water safety and sustainable usage is crucial. New guidelines are essential to prioritize water safety, making it safe for drinking purposes.

3. Rainwater Harvesting Potential as Alternative Water Supply in Malaysia

Due to the flood event in 2021, three regions in Selangor experienced unscheduled water supply disruptions due to the shutdown of the water treatment plant. In July 2022, Penang also faced water supply disruptions due to flooding and a water surge incident in Baling, Kedah. This incident should prompt the government to consider the need for an alternative water supply. As Malaysia receives abundant rainfall annually (≈ 2400 mm/year), rainwater should be stored for water supply rather than lost as runoff. The rainwater harvesting system can provide a backup water supply in the event of a disruption to the water supply. By installing rainwater harvesting technology, Malaysia can reduce the risk of flash floods and contribute to mitigation by saving water.

Table 3 summarizes the application of RWHS for water supply for domestic use in different countries. It shows that the rainwater harvesting system can meet domestic water demand, with developing countries such as Malaysia, Nigeria, and Bangladesh meeting 30-90% of their water demand, thus reducing dependence on conventional water supply. In the case study, rainwater harvesting was used to meet drinking water demand in Australia (91%) and Bangladesh (91.9%).

Table 3. Application of RWHS for water supply for domestic use.

Country	Annual Rainfall (mm)	Storage Tank (m3)	Finding	References
Australia	811	5	met 91% of drinking water demand in New South Wales	[16]
Bangladesh	2200	0.5–50	met 91.9% of drinking and cooking water demand in Dhaka	[17]
Brazil	1362	2–12	saved 12% to 79% of potable water demand in South East Brazil	[18]
	1740	20	saved 6.5% of potable water demand in Florianópolis	[19]
Colombia	1053	2	saved 44% of potable water demand in Bucaramanga	[20]
Malaysia	2400	10	saved 30% to 40% of water demand in common areas in 4 blocks of condominium comprising 965 units of apartments in Penang	[21]
	2400	10	saved 40% to 50% of water demand in Penang	[22]
	1945	160	saved 58% of water demand for community of 200 houses in Rengam, Johor	[23]
Nigeria	3553	N/A	met 80% of three-story building and 70% of bungalow water demand in Calabar	[24]

4. Technology in Rainwater Harvesting System

4.1. Filtration Technology

Harvested rainwater from catchment areas is usually contaminated with dirt, leaves, plant debris and other unwanted matter. Even if the harvested rainwater is used for non-potable purposes, it is recommended to filter the rainwater before storage. The filter is an important component of a rainwater harvesting system, as it contributes to the quality of the water. According to Ibrahim [25], the filtration process not only reduced the contaminants, but prevented the larva eggs and avoid mosquitoes breeding from entering storage tank. Numerous applications are used in the removal of fine suspended particles from rainwater, including first flush diverters [26], [27], sand [28] and activated carbon [29].

Despite the growing variety of filters for rainwater filtration on the market, there are still limitations, mainly due to the adaptability of rainwater filters in the building, clogging problems in the filter medium, energy consumption and many more. Table 4 summarizes the filter treatment suggested in the rainwater harvesting guidelines of different countries. The guidelines provide recommendations for different for different types of filter based on the desired level of filtration. In addition, many guidelines recommend the use of activated carbon to improve the taste of rainwater by removing chlorine odors. Due to activated carbon's high porosity and large surface area, it is extremely effective at adsorbing contaminants and contaminants from the water, resulting in improved taste and odor reduction.

Table 4. Filtration treatment recommended in the guidelines.

Guidelines	Filtration Process	References
Rainwater Harvesting Potential and Guideline for Texas (2006)	• Install cartridge filters after the pump to provide pressure to the plumbing system. • For potable water, use a filter that can remove at least 99 percent of particles with a diameter of 3 microns or larger. • Activated charcoal filter can be added if needed to enhance the taste of drinking water	[30]
The Texas Manual on Rainwater Harvesting (2005)	• Filtering: An in-line or multi-cartridge filter is positioned after the pump to effectively separate sediment. Activated charcoal is placed after the sediment filter to eliminate chlorine and enhance the taste of the water. A separate tank containing a slow sand filter is utilized to trap and remove particulate matter.	[31]
International Residential Code: Potable Rainwater Collection & Distribution System, Arizona	• Filtering: A roof washer is installed prior to the tank to remove suspended materials. An in-line or multi-cartridge filter is positioned after the pump to effectively separate sediment. Activated charcoal is placed after the sediment filter to eliminate chlorine and enhance the taste of the water. A separate tank containing a slow sand filter is utilized to trap and remove particulate matter.	[32]
Rainwater Treatment Guide (New South Wales, Australia)	• Filtration: To remove particulate matter and some dissolved materials from water, different filter types is used depending on the level of filtration required and the specific contaminants to be addressed i. Polypropylene & ceramic cartridge filters: Remove sediment and bacteria but cannot eliminate viruses. ii. Activated carbon filters: Reduce chemicals like iron and hydrogen sulfide, improve taste, odor, and color, but do not eliminate bacteria or viruses. iii. Micro/Ultra filtration membrane filters: Remove sediment and bacteria and specific health-related contaminants. iv. Reverse osmosis filters: Remove microorganisms and most residual chemicals, total dissolved solids and offer optional reduction claims.	[33]
Guidance on Use of Rainwater Tanks	Filtration: To maintain the quality of rainwater by addressing microbial, chemical, and physical concerns.	[34]

Table 4. Filtration treatment recommended in the guidelines *(Cont)*.

Greywater Treatment and Reuse, And Rainwater Harvesting and Collection at Home Guideline	• Filtration: Through two methods: using sand filters or passing water through membranes with narrow pores.	[35]
National Guideline for Rainwater Harvesting System	• Media filtration and micro-filtration. Carbon filter may be used after the first treatment stage.	[36]

4.2. Membrane Technology for Rainwater Harvesting

Currently, there are many modern technologies available for water treatment. Membrane technology can maximise the treatment of stormwater to achieve the water quality standard for reuse (Table 5). Liu et al. [37] studied the use of membrane technology in the treatment of harvested rainwater. It was concluded that the proposed technology could significantly improve water quality; however, the main challenge with this technology is membrane fouling.

Table 5. Types and characteristics of different membrane technologies. [37]

Types of membrane technology	Membrane pore diameter	Advantages	Disadvantages
Ultrafiltration	5–100 nm	Low energy consumption and costs; high tolerance of acid, alkali, and high temperature; high physical separation capacity.	Difficulties in handling grease; susceptibility to heavy metals.
Microfiltration	0.1–5 µm	Low hydrostatic pressure; high contaminant rejection and solvent flux.	Low removal rate of organics and pathogens with single microfiltration; need to combine with other water treatment processes.
Nanofiltration	1–2 nm	High solute retention rate; low energy consumption	Limitation of membrane materials development.
Reverse osmosis	0.1–0.7 nm	High removal rate of soluble organic pollutants;	Membrane is susceptible to contamination; need to combine with other water treatment process; high energy cost.

Heavy metals are one of the most common problems in rainwater quality. A study by Malaysian researchers found membranes have the potential to remove heavy metals and other water quality parameters. A study by Haan et al. [38] using different types of membranes, such as ultrafiltration and reverse osmosis, highlighted the potential utility of membrane technology in the treatment of mine water. The results show that the using of a single membrane unit could not meet the standard for domestic use. However, future studies with an integrated staged membrane filtration system are designed and proposed for future studies to further the improve water quality. Heavy metals such as iron and manganese are naturally present in groundwater. Kasim et al. [39], study used nano-polyamide nanofiltration and ultrafiltration membranes (PA-NF, PA-UF) to investigate their ability to treat groundwater for drinking water resources. Other studies using membrane technology include [40,41,42].

4.3. *Application of IoT Technology in Rainwater Harvesting*

In the era of Industry 4.0, the number of connected Internet of Things (IoT) devices is growing. Internet of Things (IoT) enables connections among various devices with the ability to exchange and gather data. IoT enables real-time device connectivity and data collection, resulting in higher quality measurements and more efficient information management. In addition to the automation industry using industry 4.0, IoT extends its capability to give innovative smart water management, water quality monitoring and solve environmental issues. This can be achieved through a variety of sensors and various cloud platforms controlled via the Internet of Things (IoT).

Rainwater is one of the most important sources of freshwater and is completely wasted through runoff. A way must be found to prevent freshwater from being wasted. RWHS have started to implement the Internet of Things (IoT) application for efficient rainwater harvesting. The conventional systems have some limitations, most notably the lack of control over the quality of the drinking water especially in rural areas [43]. Another common limitation of the conventional system is that the RWHS does not monitor the water leakage, filling, and emptying process [44]. In general, the filling process depends on the storage capacity and frequent rainfall events will cause the tank to overflow. As a solution, consumers should provide more reserve storage or oversize tanks for storage, but an oversize tank is probably not an economical and preferable option. The main advantages of using IoT in RWHS are the real-time monitoring for the levels and water quality of harvested rainwater. With IoT technology, water quality can be monitored in real-time, which is vital to maintaining a safe and clean water supply. By continuously monitoring water quality parameters such as pH, temperature and turbidity, changes that could indicate contamination can be quickly identified. To ensure that the devices are working properly and the data is correct, regular maintenance of the system or devices is required.

Rahmat et al. [45] investigated IoT devices were used to monitor water levels and water quality in rainwater tanks. The devices consist of sensors connected to Arduino Uno as a microcontroller board and monitored via the AgriTECH Monitoring System online portal. The output data was collected daily from the online water monitoring systems. With the application of IoT-devices, real-time tracking and monitoring can be performed to predict unusual activities such as heavy rainfall that may cause overflow.

IoT-based sensor was also used to control water levels in RWHS tanks [44]. The study found that the use of it in the tanks helped to reduce urban flooding and secure non-potable water supplies. Another IoT application in Austria, combined with a rain barrel (Smart Rain Barrel), achieved an 18-40% reduction in flood volume, with all floods and water levels measured in real time [46]. The efforts have been made in recent years to monitor water quality by examining parameters such as pH, conductivity, dissolved oxygen, temperature, biochemical oxygen demand and total dissolved solids (TDS). Real-time water quality monitoring has gained importance in RWHS for future drinking water and safety reasons.

Oberascher et al. [47] investigate innovative solutions for decentralisation of water infrastructure using low-cost sensors. A Smart Rain Barrel (SRB) concept is a micro-scale Low Impact Develoment (LID) that serves as temporary storage for stormwater control as well as for rainwater harvesting. The SRB concept was to improve rainwater collection using low-cost IoT sensors. The SRB consisted of a standard rain barrel connected to a controlled release valve and water level sensor device. The SRB concept was developed as Real-Time Control (RTC) micro storages using low power wide area technology LoRaWAN. Conventional rain barrel and SRB with a storage volume of 0.5m3 were compared. Peak runoff during rain event reduced by 80% for SRB. Meanwhile conventional barrel fully filled by the time the peak intensity is achieved. After the rainfall event, both concepts were completely filled in order to provide as much rainwater as possible for irrigation purposes.

Judeh [48] discusses smart rainwater harvesting system in Palestine, where the average annual rainfall in Palestine around 590mm/year, while the maximum annual daily rainfall is about 62.3 mm/day. It is noticeable that most of rainfall falls between October and April. The smart system architecture was introduced in the Jenin, Palestine. The proposed system has the ability to intelligently monitor water levels, water quality and water leaks, and later increase harvesting efficiency at the survey site. The smart RWHS has demonstrated its ability to meet 41% of domestic water needs. The study also demonstrated the efficiency and reliability of the dual water system compared to the smart RWHS alone.

5. Conclusion

In the face of climate change and rapid population growth, urban areas are increasingly threatened by water shortages. Embracing a rainwater harvesting system presents a sustainable and effective solution to address water security challenges. Malaysians need to be exposed to the various benefits of rainwater harvesting techniques for many uses. The awareness of Malaysian citizens on rainwater harvesting still needs to be improved and the government should make efforts to increase the campaign. The technical specification for installing the system should be explained to encourage Malaysian citizens to implement rainwater harvesting. In the future, the guidelines will need to be improved by considering water safety when the government is looking for an alternative water supply from rainwater. Rainwater harvesting systems meet non-potable and domestic water demand. Current technology, such as filtration, membrane technology and IoT, is possibly helping to improve the quality of rainwater harvesting, especially for potable water.

Acknowledgement

This work was supported by the Short-Term Grant, Universiti Sains Malaysia under grant number '304.PREDAC.6315563'. The authors also acknowledge the support by the Royal Academy of Engineering and Lloyd's Register Foundation under the "Engineering X Engineering Skills where they are Most Needed Impact Grants Call 2021/23" (Grant No. 304/PREDAC/6050508/R125) and the Higher Institution Centre of Excellence Programme (HICoE) at REDAC (Grant No. 311/PREDAC/4403901) by the Ministry of Higher Education, Malaysia.

References

[1] Tan ML, Ibrahim AL, Cracknell AP and Yusop Z 2017 Changes in precipitation extremes over the Kelantan River Basin, Malaysia *Int. J. Climatol.* **37**(10) 3780-3797
[2] Tan ML, Zhangb F, Derekc CJC, Yud KH, Shaharudine SM, Chana NW and Rahima A 2022 Spatio-temporal analysis of precipitation, temperature and drought from 1985 to 2020 in Penang, Malaysia *Water Supply* **22**(5) 4757-4768
[3] Haque MM, Rahman A, & Samali B 2016 Evaluation of climate change impacts on rainwater harvesting *J. Clean Prod.* **137** 60-69
[4] Zabidi HA, Goh HW, Chang CK, Chan, NW and Zakaria NA 2020 A review of roof and pond rainwater harvesting systems for water security: The design, performance and way forward *Water* **12**(11) 3163
[5] Rainwater Harvesting Guidebook 2009 Department of Irrigation and Drainage
[6] Mohd-Shawahid HO, Suhaimi AR, Rasyikah MK, Jamaluddin SA, Huang YF and Farah MS 2007 Policies and incentives for rainwater harvesting in Malaysia *Colloquium on Rainwater Utilization, Putrajaya, Malaysia* 19-20
[7] Hafizi MLN, Yusop Z and Syafiuddin A 2018 A review of rainwater harvesting in Malaysia: prospects and challenges *Water* **10**(4) 506
[8] Adnan A, Ahmad AC and Teriman S 2020 Rainwater Harvesting (RWH) installation for buildings: A systematic review and meta-analysis approach *Malaysian J of Sustainable Environme*nt **6**(1) 89-10
[9] Lee KE, Mokhtar M, Hanafiah MM, Halim AA and Badusah J 2016 Rainwater harvesting as an alternative water resource in Malaysia: potential, policies and development *J. Clean. Prod.* **126** 218-222
[10] Ahmed W, Gardner T and Toze S 2011 Microbiological quality of roof-harvested rainwater and health risks: a review *J. Environ. Qual.* **40**(1) 13-21
[11] Water Safety Plan Handbook for Rural Water Supply Systems 2011 Ministry of Health Malaysia.
[12] Ahmed W & Toze S 2015 Microbiological quality and associated health risks with the use of roof-captured rainwater *Rainwater tank systems for urban water supply: Design, yield, energy, health risks, economics and social perceptions* Ed Sharma AK, Begbie D, Gardner T IWA Publishing Alliance House, London, UK 229-252

[13] Denissen JK, Reyneke B, Waso M, Khan S and Khan W 2021 Human Pathogenic Bacteria Detected in Rainwater: Risk Assessment and Correlation to Microbial Source Tracking Markers and Traditional Indicators *Frontiers in microbiology* **12** 659784

[14] Hamilton K, Reynek B, Waso M, Clements T, Ndlovu T, Khan W, DiGiovanni K, Rakestraw E, Montalto, F, Haas CN and Ahmed W 2019 A global review of the microbiological quality and potential health risks associated with roof-harvested rainwater tanks *NPJ Clean Wate*r **2**(1) 7

[15] Tan ML, Ibrahim AL, Duan Z, Cracknell AP and Chaplot V 2015 Evaluation of six high-resolution satellite and ground-based precipitation products over Malaysia *Remote Sensing* **7**(2) 1504-1528

[16] Alim MA, Rahman A, Tao Z, Samali B, Khan MM and Shirin S 2020 Feasibility analysis of a small-scale rainwater harvesting system for drinking water production at Werrington, New South Wales, Australia *J. Clean Prod.* **270** 122437

[17] Karim MR 2010 Assessment of rainwater harvesting for drinking water supply in Bangladesh *Water Sci. Technol.-Water Supply* **10**(2) 243-249

[18] Ghisi E, Bressan DL and Martin M 2007 Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil *Build. Environ.* **42**(4) 1654-1666

[19] Kuntz Maykot J and Ghisi E 2020 Assessment of a rainwater harvesting system in a multi-storey residential building in Brazil *Water* **12**(2) 546

[20] Oviedo-Ocaña ER, Dominguez I, Ward S, Rivera-Sanchez L and Zaraza-Peña, JM 2018 Financial feasibility of end-user designed rainwater harvesting and greywater reuse systems for high water use households *Environ. Sci. Pollut. Res.* **25** 19200-19216

[21] Chan NW 2012 The N-Park Negalitres Project: A pilot water-saving initiative using green technology and changing water use behaviour *Water and the Green Economy* **75**

[22] Chan NW 2019 Holistic urban water management integrating rainfall harvesting, Water conservation and sustainable drainage systems in Universiti Sains Malaysia *Proceedings of the 5th International Conference on Advances in Environment Research (ICAER 2019), Singapore* 13-15

[23] Hashim H, Hudzori A, Yusop Z and Ho WS 2013 Simulation based programming for optimization of large-scale rainwater harvesting system: Malaysia case study *Resour. Conserv. Recycl.* **80** 1-9

[24] Nnaji CC and Mama N 2014 Preliminary assessment of rainwater harvesting potential in Nigeria: Focus on flood mitigation and domestic water supply *Water Resour. Manag.* **28** 1907-1920

[25] Ibrahim SH, Yaman K, Wahab RA Nasrun M and Nawi M 2017 Filtration of Rainwater Harvesting System in Rural Area *J. Eng. Sci. Technol.* **12** 181-191

[26] Morgado ME, Hudson CL, Chattopadhyay S, Ta K, East C, Purser N, Allard S, Ferrier MD, Sapkota AR, Sharma M and Goldstein RR 2022 The effect of a first flush rainwater harvesting and subsurface irrigation system on E. coli and pathogen concentrations in irrigation water, soil, and produce *Sci. Total Environ.* 843 156976

[27] Van der Sterren M, Rahman A and Denni GR 2013 Quality and quantity monitoring of five rainwater tanks in Western Sydney *Australia Journal of Environmental Engineering* **139** (3) 332-340

[28] Neto RFM, Calijuri ML, de Castro Carvalho I. and Da Fonseca Santiago A 2012 Rainwater treatment in airports using slow sand filtration followed by chlorination: efficiency and costs. *Resour. Conserv. Recycl* **65** 124-129

[29] Kus B, Kandasamy J, Vigneswaran S, Shon H and Moody G 2012 Two stage filtration for stormwater treatment: A pilot scale study *Desalin. Water Treat.* **45** (1-3) 361-369

[30] Rainwater Harvesting Documents 2006 Texas Water Development Board https://www.twdb.texas.gov/innovativewater/rainwater/docs.asp

[31] Rainwater Harvesting Manual 3rd 2005 Edition Texas Water Development Board (TWDB) https://www.twdb.texas.gov/publications/brochures/conservation/doc/RainwaterHarvestingManual_3rdedition.pdf

[32] User Guide for Potable Rainwater Harvesting 2018 Arizona: Coconino County https://www.coconino.az.gov/DocumentCenter/View/44527/User-Guide-for-Potable-Rainwater-Harvest
[33] Rainwater Treatment Guide The New South Wales Ministry of Health, https://www.health.nsw.gov.au/environment/water/Documents/Rainwater-Treatment-Guide.pdf
[34] ENHealth Guidance: Guidance on the Use of Rainwater Tanks 2022 Australian Government Department of Health https://www.health.nsw.gov.au/environment/water/Documents/Rainwater-Treatment-Guide.pdf
[35] Greywater Treatment and Reuse, And Rainwater Harvesting and Collection 2018 The Royal Scientific Society https://www.researchgate.net/publication/325499152_Guideline_for_greywater_treatment_and_reuse_and_rainwater_harvesting_and_collection_at_home_-_English_Version
[36] UNDP and Lebanese Republic, Ministry of Energy and Water 2016 National Guideline for Rainwater Harvesting System. Lebanon: Ministry of Energy and Water
[37] Liu X, Ren Z, Ngo HH, He X, Desmond P and Ding A 2021 Membrane technology for rainwater treatment and reuse: A mini review *Water Cycle* **2** 51-63
[38] Haan TY, Mohammad AW, Ramli S, Sajab MS and Mazuki NIM 2018 Potential of membrane technology for treatment and reuse of water from old mining lakes *Sains Malaysiana* **47**(11) 2887-2897
[39] Kasim N, Mohammad AW and Abdullah SRS 2017 Iron and manganese removal by nanofiltration and ultrafiltration membranes: influence of pH adjustment *Malaysian Journal of Analytical Sciences* **21**(1) 149-158
[40] Kasim N, Mohammad AW and Abdullah SRS 2016 Characterization of hydrophilic nanofiltration and ultrafiltration membranes for groundwater treatment as potable water resources *Desalin. Water Treat.* **57**(17) 7711-7720
[41] Hubadillah SK, Othman MHD, Kadir SHSA, Jamalludin MR, Harun Z, Abd Aziz MH, Rahman MA, Jaafar J, Nomura M, Honda S and Iwamoto Y, 2019 2019 Removal of As (III) and As (V) from water using green, silica-based ceramic hollow fibre membranes via direct contact membrane distillation. *RSC advances* **9** (6) 3367-3376
[42] Kumar M, RaoT S, Isloor AM, Ibrahim GS, Ismail N, Ismail AF and Asiri AM 2019 Use of cellulose acetate/polyphenylsulfone derivatives to fabricate ultrafiltration hollow fiber membranes for the removal of arsenic from drinking water *Int. J. Biol. Macromol.* **129** 715-727
[43] Dao DA, Tran SH, Dang HT, Nguyen VA, Nguyen VA, Do CV and Han M 2021 Assessment of rainwater harvesting and maintenance practice for better drinking water quality in rural areas *AQUA—Water Infrastructure, Ecosystems and Society* **70**(2) 202-216
[44] Behzadian K, Kapelan Z, Mousavi SJ and Alani A 2018 Can smart rainwater harvesting schemes result in the improved performance of integrated urban water systems? *Environ. Sci. Pollut. Res.* **25** 19271-19282
[45] Rahmat SN and Looi ZH 202 Monitoring Water Level and Water Quality in Rainwater Harvesting Tank using Internet of Things (IoT) Device *Journal of Advancement in Environmental Solution and Resource Recovery* **2**(2) 64-74
[46] Oberascher M, Zischg J, Palermo SA, Kinzel C, Rauch W and Sitzenfrei R 2019 Smart rain barrels: Advanced LID management through measurement and control *New Trends in Urban Drainage Modelling: UDM 2018 11* Springer International Publishing 777-782
[47] Oberascher M, Kinzel C, Kastlunger U, Kleidorfer M, Zingerle C, Rauch W and Sitzenfrei R 2021. Integrated urban water management with micro storages developed as an IoT-based solution–The smart rain barrel *Environ. Modell. Softw.* **139**105028
[48] Judeh T, Shahrour I and Comair F 2022 Smart Rainwater Harvesting for Sustainable Potable Water Supply in Arid and Semi-Arid Areas *Sustainability* **14**(15) 9271