e-Bangi Faculty of Social Sciences and Humanities Universiti Kebangsaan Malaysia
Journal of Social Sciences and Humanities

eISSN: 1823-884x

Volume 22, Issue 4, DOI: https://doi.org/10.17576/ebangi.2025.2204.42

Review Paper

Rainwater Harvesting in Universities: A Systematic Review of Applications and Benefits

Mohd Sharmizi Shaferi[1], Frankie Marcus Ata[1]*, Mohd Ekhwan Toriman[2,3], Mir Sujaul Islam[4] & Dona Raihana Don Ramli[1]

[1]Program Geografi, Pusat Kajian Pembangunan, Sosial dan Persekitaran, Fakulti Sains Sosial dan Kemanusiaan, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[2]Pusat Perundingan Strategik Antarabangsa dan Matlamat Pembangunan Mampan, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[3]Akademi Kepimpinan Pendidikan Tinggi, Kementerian Pendidikan Tinggi, 71760 Bandar Enstek, Malaysia
[4]Institut Alam Sekitar dan Pembangunan, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

*Corresponding Author: frankie@ukm.edu.my

Received: 12 September 2025
Accepted: 15 November 2025

Abstract: Rainwater harvesting system (RWHS) is one of the Best Management Practices (BMP) that provides alternative water resources and has emerged as a sustainable solution to address diverse water management challenges. This study systematically reviews the application of RWHS as an alternative water resource in universities, guided by two objectives: to identify the types of RWHS applied and to discuss their importance in supporting sustainable water management. The review followed five methodological stages: review protocol selection, research question development, systematic database searching (Web of Science and Scopus), quality appraisal, and data extraction and analysis. From 987 initial records, 13 articles were selected, revealing five RWHS types: rooftop, surface runoff, small-scale, wind-driven, and permeable pavement systems. Rooftop RWHS was the most applied and cost-effective, while surface and pavement systems were least implemented but offered dual benefits of runoff reduction and groundwater recharge. The review identifies several research gaps, including the lack of studies on long-term system performance, governance, and integration of RWHS within university sustainability frameworks. RWHS provides environmental benefits through water conservation, flood mitigation, and groundwater recharge, alongside economic advantages such as reduced utility costs and operational savings. Future research should conduct comparative and multi-regional analyses, assess innovative RWHS designs, and evaluate institutional and policy frameworks to strengthen the integration of RWHS into higher education sustainability initiatives.

Keywords: Rainwater harvesting system; university; environmental benefits; economic benefits; systematic review

Introduction

Rainwater Harvesting System (RWHS) is a system that collects rainwater from the catchment area and then stores it in a storage tank for future purposes (Jalil et al., 2024; Mostaffa et al., 2021). The RWHS is a traditional method of water conservation that has been used for thousands of years (Goh & Ideris, 2021; Richardson, 2024). Generally, the simplest way to establish the RWHS is to put the container, like barrels, in open space, and it will catch and store the water during rainfall (Goh, 2008). Recently, the development in technologies has led to the development of assorted types of RWHS, such as direct pumped RWHS, indirect pumped RWHS and indirect gravity RWHS (Rainharvesting Systems, 2023). Alternatively, building walls (Samzadeh et al., 2021) and permeable pavements (Vaz et al., 2021) can now be used as catchment area for RWHS instead of rooftops.

Due to its cost-effective and sustainable features, the system has become a promising option to address water shortage and growing future water demands that may ease the pressure on existing water resources (Richards et al., 2021). Therefore, it has been widely adopted as an alternative water resource in many countries such as the United States of America, Japan, China, India, Germany and Australia (Che-Ani et al., 2009). As a result, numerous studies have investigated the system in various countries. For instance, few previous studies focused on the viability of the RWHS, addressing a range of aspects, such as its technical performance in Iran (Kolavani & Kolavani, 2020), economic feasibility in Australia and Kenya (Amos et al., 2016) and its social relevance in term of religious purposes such as ablution in Brunei Darussalam (Kapli et al., 2023). In connection with positive outcomes from previous studies, RWHS has gained attention from various stakeholders including universities. The growing interest roots from its potential to support universities' sustainable agenda, more specifically to enhance sustainable water management within campus area.

Aligned with the global sustainability framework, universities move forward in developing eco-friendly initiatives, such as RWHS, to support sustainability frameworks. Latest studies highlight that sustainability frameworks, including the UI GreenMetric World University Ranking, QS Sustainability Rankings and Times Higher Education (THE) Impact Rankings, transform green infrastructure and water management practices as the primary focus for universities worldwide to maintain and support their environmental performance indicator (Aregarot et al., 2024; Dawodu et al., 2022; Domingos et al., 2024). In response to being well-positioned within these frameworks, many universities begin to embed RWHS within their campus sustainability frameworks as two-pronged solutions, both to support sustainable water management strategies and to achieve the best rankings. The action positions RWHS not merely as a technical solution, but also as a strategic aspect in contributing to the Sustainable Development Goals (SDGs), especially SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action) (Suni et al, 2025).

Despite the needs in supporting sustainability frameworks by implementing RWHS, there are still limited studies on its use within university campuses area. However, there were few related previous studies regarding this system in university campuses such as rainwater harvesting quality assessment (Abuelfutouh et al., 2020), technical and financial feasibility of RWHS (Cardoso et al., 2020; Jian et al., 2021), and the observation of types of rainwater and its runoff (Soni et al., 2022; Yoo et al., 2022). Although there is still lack of comprehensive studies that discuss and analyse RWHS implementation in sustainability frameworks and peformance in universities, this review will deliver valuable insights into the technical and operational aspects of RWHS. This specifies a research gap in understanding how RWHS benefits strategically to sustainable campus development and aligns with global sustainability goals. A limited number of studies have brought up this topic to light, which aims to conduct a systematic literature review on RWHS application in universities and its benefits. The findings of this review could potentially guide future research, inform policy decisions, and contribute to the sustainable development of universities' water management systems, especially in universities.

Thereby, the current study aims to conduct a systematic literature review on the application of RWHS for alternative water resources in universities. Two research objectives have been set where the first objective is to identify the RWHS application in universities while the second objective is to discuss the importance of RWHS as part of the alternative water resources in the campus.

Methodology

1. Selection of the Review Protocol

The SLR was performed based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) methodology. The PRISMA was chosen because of its broad recognition in several fields and disciplines worldwide (Azmi et al., 2023). Therefore, its recommendations have been widely adopted and applied in any SLR (Trifu et al., 2022).

2. Development of the Research Questions

Research questions are essential to conduct the process of SLR. By applying PICo method, clear and better research topics and research questions for any SLR can be developed (Azmi et al., 2023). The PICo method is the Research Question Development Tools (RQDT) that combines three elements: 'P' for Problem or Population, 'I' for Interest, and 'Co' for Context (Hosseini et al., 2024; Shaffril, 2020). Based on this RQDT, the current study involved three elements which are 'alternative water resources' as the problem, 'rainwater harvesting system' as the interest, and 'universities' as the context. Therefore, the research questions developed for the study were: i) what are the types of rainwater harvesting systems applied in universities? and ii) what are the importance of rainwater harvesting systems applied in universities?

3. Systematic Searching Strategies

The selection process was divided into four stages: database selection, paper extraction, abstract screening and full-text screening. A process for the paper selection is illustrated in the PRISMA flow diagram in Figure 1. Referring to Figure 1, the identification process involved selecting the databases to be used for documents searching. The searching process was then followed by screening process. The screening process can be divided into four steps: screening documents based on criteria, abstract assessment, full-text assessment and quality appraisal. After screening, the remaining documents were included for review.

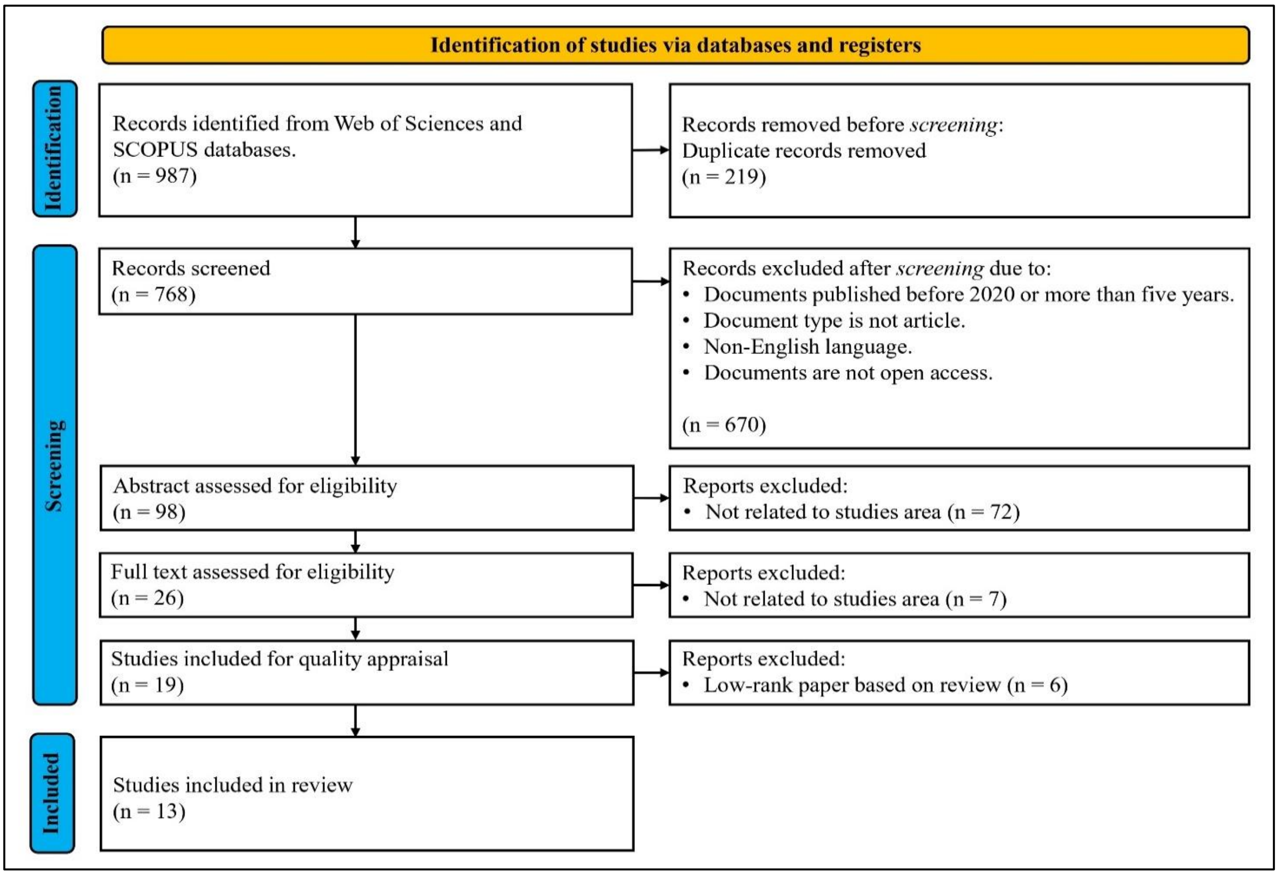

Figure 1. A PRISMA flow diagram of the systematic searching process

Identification

In the identification process, relevant keywords were located based on research questions and this process was similar to the previous SLR done by Azmi et al. (2024) and Azmi et al. (2023).The keywords were then combined into search strings, as shown in Table 1. The search strings were used to perform the searching process in the databases. The searching process involved two types of databases which were Web of Sciences (WoS) by Thomson Reuters and Scopus by Elsevier (Scopus, n.d.; Web of Science, n.d.). The reason for choosing both databases was because the high quality journal is perceived in WoS and SCOPUS as the databases would index only the highest quality sources under strict and carefully screening procedures (Institute for Educational Research and Publication, 2022).

After the search strings in Table 1 were applied into both databases, an amount of 987 results or documents were found. However, after removing 219 results that were duplicated or repeated, only 768 results were screened in the next process.

Table 1. The search strings

Databases	**Search Strings**
Scopus	TITLE-ABS-KEY("rainwater harvest*" OR "rain harvest*" OR "rainwater harvest* system*" OR "rain harvest* system*" OR "RWH" OR "RWHS" OR "rainwater collect*" OR "rain collect*" OR "rainwater capture*" OR "rain capture*" OR "rainwater utili*e*" OR "rain utili*e*" OR "rainwater recycle*" OR "rain recycle*" OR "rainwater store*" OR "rain store*" OR "rainwater manage*" OR "rain manage*" OR "rainwater conserve*" OR "rain conserve*" OR "rainwater recover*" OR "rain recover*" OR "rainwater catchment" OR "stormwater harvest*" OR "stormwater manage*" OR "stormwater collect*" OR "stormwater capture*" OR "stormwater utili*e*" OR "stormwater recycle*" OR "stormwater store*" OR "stormwater recover*") AND ("university*" OR "campus*" OR "campus* build*" OR "higher education campus*" OR "institute*" OR "institute* build*" OR "higher education institute*" OR "academic institute*" OR "educational institute*" OR "higher learning institute*" OR "public university*" OR "faculty*" OR "university* build*")
WoS	TS=(("rainwater harvesting" OR "rain harvesting" OR "rainwater harvesting system" OR "rain harvesting system" OR "RWH" OR "RWHS" OR "rainwater collection" OR "rain collection" OR "rainwater capture" OR "rain capture" OR "rainwater utilization" OR "rain utilization" OR "rainwater recycling" OR "rain recycling" OR "rainwater storage" OR "rain storage" OR "rainwater management" OR "rain management" OR "rainwater conservation" OR "rain conservation" OR "rainwater recovery" OR "rain recovery" OR "rainwater catchment" OR "stormwater harvesting" OR "stormwater management" OR "stormwater collection" OR "stormwater capture" OR "stormwater utilization" OR "stormwater recycling" OR "stormwater storage" OR "stormwater recovery") AND "non-conventional water resources" OR "substitute water sources" OR "additional water sources" OR "Alternative water reserves" OR "alternative water sources" OR "alternative water resources") AND ("university" OR "campus" OR "campus buildings" OR "higher education campus" OR "institute" OR "institute buildings" OR "higher education institute" OR "academic institute" OR "educational institute" OR "higher learning institute" OR "public university" OR "faculty" OR "university buildings"))

Screening

Subsequently, the procedure was followed by screening process. The screening process is a two-part process in which the researchers determine the results whether its meet the criteria for SLR (University of South Australia, n.d.). The remaining 768 papers from the identification process were filtered based on these criteria: 1) documents published between 2020 and 2024 (5 years period), 2) document types (only article considered for the SLR), 3) English paper only, and 4) open access only. Through this filtering process, 670 papers were excluded for the SLR, and 98 papers left will be assessed for the next stage which is the eligibility process.

Eligibility

The eligibility process was the next process after screening in conducting this SLR which involved the manual examination of the papers by the researchers. This process aims to confirm that all the remaining articles meet the requirements. The process involved the abstract assessment to verify whether the papers were suitable for the review. Through the abstract assessment, only 26 papers were selected for the next stage assessment (full-text assessment) after excluding 72 papers that were not related to the study. The remaining papers were assessed for full-text assessment and after the process, only 19 papers will be ranked through quality appraisal procedure.

Quality Appraisal

The quality appraisal is the last process in determining whether the selected papers from previous process were suitable for the SLR or not. The quality of the articles was assessed through a quality appraisal procedure. This process will make sure that the SLR has a credibility and lower the risk of bias in conducting the SLR (Ali & Usman, 2019). Every article included in quality appraisal followed the practices adapted by Kolaski et al. (2023) and Muchadeyi et al. (2024). Following the frameworks and practices established by these studies, a quality appraisal was conducted by assessing how the reporting was done, the relevance of the study, the methodologies' quality and certainty of the studies.

The remaining 19 papers from eligibility procedure were examined by two chosen reviewers. First reviewer was the lecturer that experienced in hydrology projects for over three years and teaching hydrology and geography studies for more than two years. Another reviewer was a university colleague pursuing doctorate studies. The remaining articles were divided into three quality categories which are high, moderate and low. Only the high and moderate rank articles were reviewed in this SLR. Subsequently, only 13 articles will be included in this study while the low rank papers will be excluded.

Data Extraction and Analysis

Systematically, data extraction was carried out for every selected articles. This process was done to ensure the consistency and reliability of this study. The data extraction process invloves summarising, integrating, and combining the findings based on the research questions (Afifi et al., 2023; Azmi et al., 2023). After extracting data, the key findings were organized into Microsoft Excel for comparison and synthesis. Subsequently, a thematic analysis was conducted to align the key findings with the review's objectives, specifically the application of RWHS in universities and its benefits as an alternative water resource in supporting campus sustainability. The thematic analysis is a widely used method for analysing qualitative data offeres a structured and flexible approach to interpreting the key findings (Kiger & Varpio, 2020; Naeem et al., 2023).

The Findings

1. Background of the Selected Studies

The study has identified 13 articles from various locations worldwide. The spatial distribution of the selected studies is illustrated in Figure 2, highlighting the geographical locations where RWHS was implemented across universities. As seen in Figure 2, most studies were conducted in Malaysia, India, and Brazil, indicating that RWHS adoption is more prevalent in tropical and water-stressed regions. Four articles located in Malaysia was analysed which were refering to study done by Abuelfutouh et al. (2020), Samzadeh et al. (2021), Musa et al. (2022) and Mostaffa et al. (2021). Meanwhile, three articles analysed were located in Brazil which were referring to the study conducted by Cardoso et al. (2020), Vaz et al. (2021) and Da Silva et al. (2022). Another two papers which were the study by Kumar et al. (2022) and Ahmad et al. (2022) were the studies conducted in Pakistan while two papers were identified in India (Anchan & Prasad, 2021; Garg et al., 2022). An article by Bouzidi et al. (2024) was located in Morocco and an article by Yoo et al. (2022) was identified in South Korea.

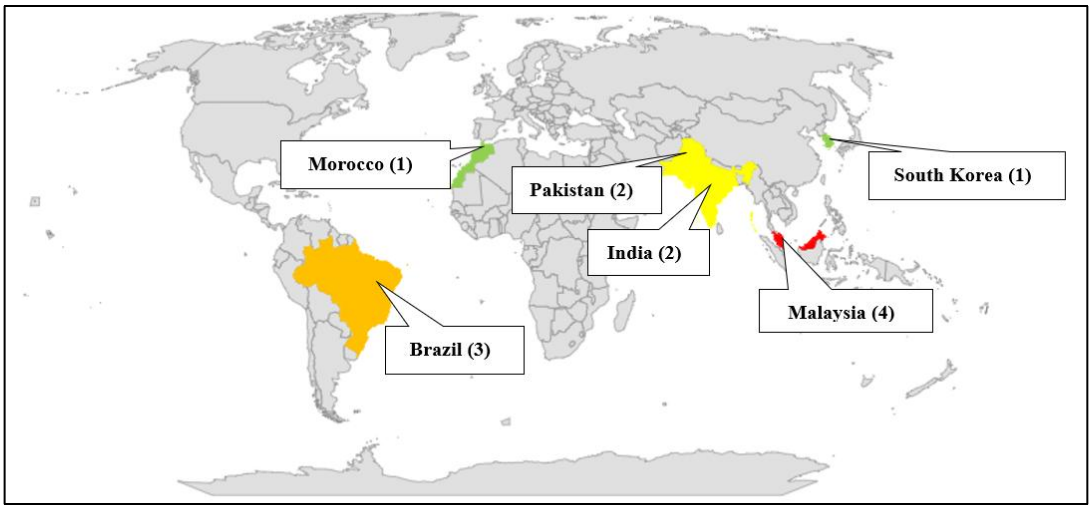

Figure 2. Spatial distribution of the selected studies

The publication trend of RWHS studies by year is illustrated in Figure 3, showing the temporal growth of research interest in this topic. Based on Figure 3, the number of publications related to RWHS in the setting of universities increased steadily from 2020 to 2022, showing growing interest in this research area. However, a noticable decline in publications after 2022 suggests that research attention toward RWHS in the context of universities has slowed in recent years. The temporal distribution of the selected articles, published according to years, was as follows; in 2024, only one articles were published which this study was done by Bouzidi et al. (2024). Same as 2024, in 2023, there was only one article published (Da Silva et al., 2022). Most of the selected articles were published in 2022. In 2022, there were five papers were published which the studies were conducted by Garg et al. (2022), Kumar et al. (2022), Yoo et al. (2022), Musa et al. (2022) and Ahmad et al. (2022). Another four articles done by Anchan & Prasad (2021), Samzadeh et al. (2021), Mostaffa et al. (2021) and Vaz et al. (2021) were published in 2021 meanwhile two articles by Abuelfutouh et al. (2020) and Cardoso et al. (2020) were published in 2020.

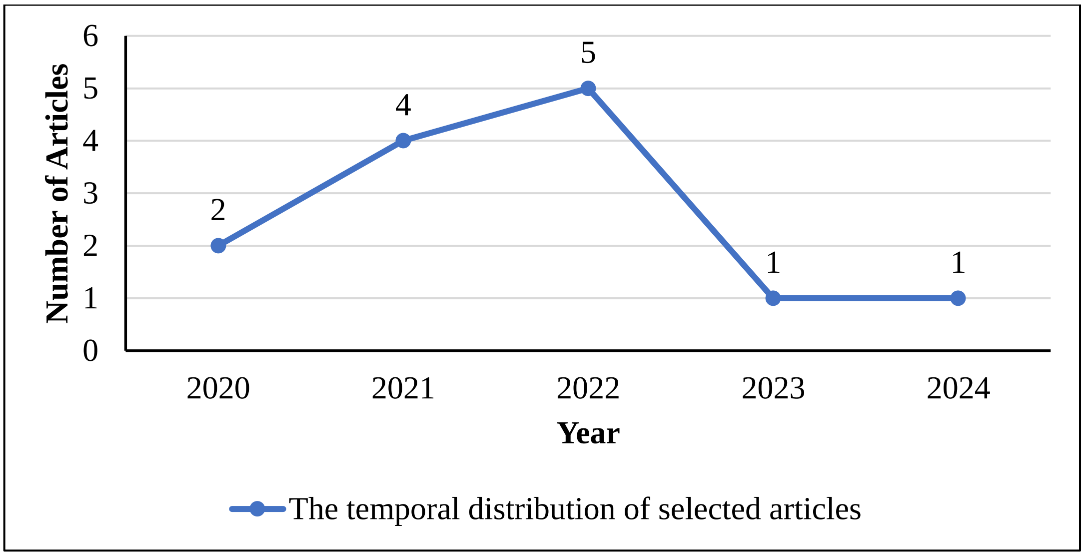

Figure 3. Publication trend of RWHS studies in universities by year (2020–2024).

In terms of methodology used to conduct studies, among the 13 selected articles, 12 articles applied mixed methodology, which involved both quantitative and qualitative methods. Only one paper applied a pure quantitative methods, which involved observation to conduct their study (Afzal et al., 2022). Figure 4 illustrates the distribution of methodologies used in the selected studies. As shown in Figure 4, 43% of the articles applied qualitative methods, including interviews and observations, while 40% of the articles applied qualitative, including the experimental design and survey method. Meanwhile, 17% of the articles utilized document analysis as the main research.

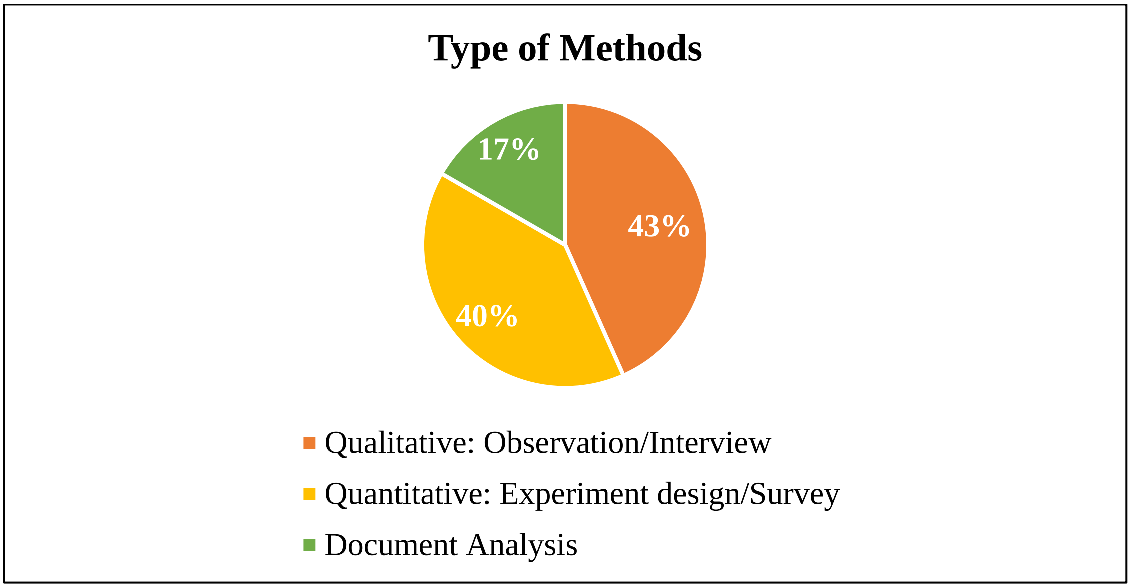

Figure 4. Method used in selected articles

2. Thematic Analysis

The analysis conducted for the 13 articles was classified into two parts which were to identify the types of rainwater harvesting systems applied in universities and to discuss the importance of rainwater harvesting systems in universities. The types of rainwater harvesting systems formed three important topics from the thematic analysis which consisted of rooftop RWHS, surface RWHS, wind-driven RWHS and small-scale RWHS. Concurrently, the second part of this review discussed the importance of rainwater harvesting systems in universities.

3. Types of RWHS Applied in Universities

As shown in Table 2, rooftop RWHS is a prevalent method where rainwater is collected from buildings roofs. The rooftop RWHS was widely applied and most of the selected articles were the studies on this type of RWHS (Abuelfutouh et al., 2020; Ahmad et al., 2022; Anchan & Prasad, 2021; Bouzidi et al., 2024; Cardoso et al., 2020; Da Silva et al., 2022; Garg et al., 2022; Kumar et al., 2022). Various roof types, including flat and sloped roofs, are utilized, with materials such as metal, tile, and asphalt influencing water quality of the RWHS. Methods of directing water from roofs to storage tanks include gutters, downspouts, and diverters, ensuring efficient collection and minimal loss. The studies conducted by Da Silva et al. (2022), Anchan & Prasad (2021) and Cardoso et al. (2020) were very focused on the potential and feasibility of the rooftop RWHS in universities campus. Even though Kumar et al. (2022) and Ahmad et al. (2022) were also focused on the potential of the system, but the approaches to assess the potential were related to application of Geographic Information System (GIS). Abuelfutouh et al. (2020) was a study regarding the rooftop RWHS but focused on the quality of the harvested water while Garg et al. (2022) was study on design of suitable rooftop RWHS for specific block in the campus. Other than that, study by Bouzidi et al. (2024) was to valuate and manage the existing rooftop RWHS applied in the university.

Other than rooftop RWHS, there were still other types of RWHS but rarely applied in the university campuses. Surface RWHS was one of the types of RWHS studied in one of the selected articles Kumar et al. (2022) which was focusing on recharging the groundwater storage through this system. Furthermore, small-scale RWHS was the type of system that some universities campus used for external purposes or non-potable usage. Small-scale RWHS was studied by Musa et al. (2022) and has been evaluated into an innovation of aesthetic small-scale RWHS called E-SPAH by Mostaffa et al. (2021). Apart from that, the RWHS has been developed and instead of using rooftop and ground surface as catchment area, the buildings wall now can be beneficial for RWHS. This was known as wind-driven RWHS, and it was studied by Samzadeh et al. (2021) and Yoo et al. (2022). Besides, permeable pavement water harvesting was one of the RWHS that rarely applied but beneficial to be developed by universities (Vaz et al., 2021).

Table 2. Summary of RWHS applications in universities

RWHS Type	Location	Findings	Benefits or Limitations	References
Rooftop RWHS	Brazil, India, Malaysia, and Pakistan	Focused on feasibility, design, and water quality of rooftop systems in universities. Some studies used GIS for site suitability.	Cost-effective and practical for non-potable uses; limited storage and rainfall dependency.	Garg et al. (2022), Da Silva et al. (2022), Anchan & Prasad, (2021), Kumar et al., (2022), Abuelfutouh et al. (2020), Cardoso et al. (2020), Ahmad et al. (2022) and Bouzidi et al. (2024)
Surface Runoff RWHS	Pakistan	Examined surface runoff harvesting for groundwater recharge.	Good for large-scale recharge; needs regular maintenance and open space.	Kumar et al. (2022)
Small-Scale RWHS (E-SPAH System)	Malaysia	Developed a compact, aesthetic system for outdoor and non-potable use.	Easy to install and efficient; small storage capacity.	Musa et al. (2022) and Mostaffa et al. (2021)
Wind-Driven / Wall-Integrated RWHS	Malaysia, and South Korea	Used building façades as catchment areas for water collection.	Space-saving and aesthetic; less efficient in low rainfall.	Samzadeh et al. (2021) and Yoo et al. (2022)
Permeable Pavement RWHS	Brazil	Applied permeable pavements to collect and reuse stormwater.	Reduces runoff and improves quality; high setup cost.	Vaz et al. (2021)

As summarised in Table 2, each RWHS types offers distinct benefits and limitations based on its design and the conditions of the site. Rooftop RWHS remain as the most prevalent option due to its practicality and cost-effectiveness, though it is suitable for non-potable usage and limited by rainfall variability and storage capacities (Raimondi et al., 2023; Sultana, 2022). Another alternatives are surface runoff and permeable pavement systems due to their function in reducing runoff and at the same time recharging groundwater. The only limitations are it requires large catchment areas and costs more to install (Bateni et al., 2022; Deke at al., 2021). Furthermore, small-scale and wall-integrated systems are types of innovative RWHS due to their suitability for limited space. However, they collect limited volumes of rainwater, making them suitable only for localised and supplementary use (Musa et al. 2022; Samzadeh et al., 2021). In all, each type of RWHS contributes in different ways despite the limitations that occured.

3. Importance of RWHS Applied in Universities

Based on the selected articles, the RWHS itself presented not only environmental advantages, but also economic advantages for educational institutions like universities. In term of environment advantages, these systems contribute significantly by reducing annual water consumption and serving as alternative resources during water crises (Cardoso et al., 2020; Da Silva et al., 2022). In addition, it met universities' society's growing demand for water resources and supplementing conventional water supplies (Ahmad et al., 2022; Anchan & Prasad, 2021). Moreover, RWHS helped in managing stormwater effectively, mitigating flooding, which are particularly crucial for campuses with extensive roof surfaces (Kumar et al., 2022; Vaz et al., 2021). By promoting water conservation, groundwater recharge, and alleviating strain on urban drainage systems, RWHS emerges as sustainable solutions that align with environmental preservation goals (Mostaffa et al., 2021; Musa et al., 2022).

On the side of economic advantages, RWHS offered substantial cost savings by reducing utility bills using harvested rainwater for non-potable purposes and irrigation needs (Abuelfutouh et al., 2020; Bouzidi et al., 2024). Their cost-effectiveness is further recognized by low payback amounts, compact designs, and the ability to upgrade capacity as per rainwater potential, making them viable options for decentralized water maintenance in educational settings (Da Silva et al., 2022; Garg et al., 2022) . These economic benefits, coupled with environmental advantages, put rainwater harvesting as a strategic investment that not only saved on operational costs but also fostered long-term resilience and sustainability in water management practices at universities (Anchan & Prasad, 2021).

Discussions

1. Analysis and Research Gaps

The review outcomes highlight that while rooftop RWHS dominates research in university settings, the emphasis across studies varies considerably in terms of feasibility, design, and performance focus. Studies in tropical countries such as Malaysia and Brazil, for example, emphasize system efficiency and rainfall abundance, whereas those in semi-arid regions like Pakistan focus more on water scarcity adaptation and groundwater recharge. This divergence indicates that while RWHS is globally recognized as a sustainable technology, its application remains context-specific and influenced by local climatic and institutional conditions. Such variation underscores the need for comparative cross-regional assessments to establish standardized evaluation metrics for RWHS performance in higher education institutions.

This prevalence is highlighted by numerous studies (Abuelfutouh et al., 2020; Ahmad et al., 2022; Anchan & Prasad, 2021; Bouzidi et al., 2024; Cardoso et al., 2020; Da Silva et al., 2022; Garg et al., 2022; Kumar et al., 2022). These studies show the system practicality and effectiveness in capturing rainwater for various campus needs like building maintenance, landscaping, and cleaning. The utilization of diverse roof types and materials, complemented by efficient water collection mechanisms such as gutters and downspouts, ensures optimal functionality while minimizing water loss, thus highlighting the robustness of rooftop RWHS in addressing water sustainability challenges in educational institutions.

Moreover, a growing interest is evident in exploring the potential and feasibility of rooftop RWHS, with some studies focusing on crucial aspects like water quality assessment (Abuelfutouh et al., 2020) and employing advanced technologies like Geographic Information System (GIS) for spatial analysis (Ahmad et al., 2022; Kumar et al., 2022). These approaches not only enhance the understanding of rooftop RWHS performance but also provide valuable insights into optimizing their design and operation. Additionally, the emergence of innovative RWHS types, such as surface RWHS, small-scale RWHS, wind-driven RWHS, and permeable pavement water harvesting, signifies a progressive shift towards exploring alternative and sustainable water management solutions tailored to the unique needs of university environments. However, instead of the studied type of RWHS in the reviewed articles, there are still few types that are not discovered by any researchers such as the green roof RWHS, large-scale RWHS and subsurface RWHS.

The dual-fold benefits of RWHS, encompassing environmental conservation and economic efficiency, underscore their pivotal role in university campuses. From an environmental standpoint, RWHS significantly contributes to water conservation, stormwater management, and groundwater recharge, aligning closely with global sustainability objectives (Teston et al., 2022). Economically, these systems offer substantial cost savings through reduced utility bills and decentralized water maintenance, making them strategic investments for long-term resilience and sustainability in university water management practices (Lani et al., 2018). However, further research and implementation efforts are essential to fully realize the potential of RWHS across different types and scale their benefits optimally in diverse university settings, paving the way for enhanced water security and sustainable development.

One notable aspect of the evolving RWHS in university campuses is the integration of smart technologies and data-driven approaches. With the advent of Internet of Things (IoT) technology and real-time monitoring systems, RWHS can now be managed and optimized with greater precision and efficiency. For instance, sensors can be deployed to monitor rainfall patterns, water quality, and storage tank levels, allowing for proactive management and timely interventions (Oberascher et al., 2022). This integration not only enhances the operational effectiveness of RWHS but also facilitates data-driven decision-making, leading to improved resource allocation and performance optimization through forecast-informed, real-time control strategies (Xu et al., 2020). Furthermore, advancements in predictive modeling and machine learning algorithms can further enhance the predictive capabilities of RWHS, enabling more accurate forecasting of water availability and demand, ultimately enhancing the resilience and adaptive capacity of university water management systems (Filho et al., 2024).

On the other hand, implementing a knowledge and culture of water stewardship and awareness is a vital way to make sure that implementation and sustainability of RWHS in university campuses is successful. Educational programs such as campaigns, workshops, and outreach programs can play a pivotal role in raising awareness of the benefits of RWHS as well as promoting water conservation practices and encouraging active participation from whole campus society (Augustine & Hanafiah, 2019; Hunt et al., 2021). Incorporating water sustainability principles into curriculum frameworks, research initiatives, or campus policies can also reinforce the importance of RWHS as integrated components of holistic water management strategies. By nurturing a knowledge and culture of water management, the higher educational institutions will not only be enhancing the benefits of RWHS but also cultivating a sense of responsibility and empowerment among campus stakeholders towards achieving water security and sustainability goals (Muhiddin et al., 2023).

The review identified several gaps in current research despite its increasing acceptence of RWHS benefits. Most studies identify technical and feasibility aspects but there is still limited focus on long-term performance evaluation, governance mechanisms, and user engagement to implement RWHS in universities. Additionally, there is also a lack of studies integrating RWHS into broader institutional sustainability frameworks such as UI GreenMetric or THE Impact Rankings. Few comparative analyses have been conducted between developed and developing regions, and studies rarely assess the social acceptance or maintenance challenges of RWHS in campus environments. Addressing these gaps will provide a more holistic understanding of RWHS implementation and its contribution to sustainable campus management.

2. Limitation of the Review

This review was limited to peer-reviewed journal articles indexed in Scopus and Web of Science databases, which may have excluded relevant studies published in other databases or institutional repositories. Only articles written in English were considered, potentially introducing language bias by excluding significant work published in non-English contexts. Furthermore, gray literature such as technical reports, theses, and policy documents was excluded to maintain quality control, which may limit the comprehensiveness of practical implementation insights. It is suggested for future reviews to expand the scope by incorporating gray literature and multilingual studies to provide a more inclusive understanding of RWHS practices across diverse academic and geographical settings.

Conclusion

In conclusion, this SLR reveals that RWHS offers significant environmental and economic benefits when implemented in university settings. However, there is still scarcity of RWHS research focusing specifically on universities despite the wide adoption of RWHS in several fields. This research gap highlights the necessity for more comprehensive studies to explore the challenges and opportunities of RWHS implimentation within the academic institutions such as universities. The review contributes new insights by identifying that while rooftop RWHS remains the most widely applied system due to its cost-effectiveness and practicality, alternative systems such as permeable pavement and wall-integrated RWHS show strong potential for future applications because of their dual-functionality and adaptability in limited spaces. The advancement of technology has led to the development of diverse RWHS types, enhancing their feasibility and effectiveness.

From a policy perspective, the review recommends that university planners integrate RWHS initiatives into institutional sustainability frameworks and green campus policies to improve water efficiency, reduce operational costs, and align with SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action). As a centre of higher education, research and innovation, universities have the potential to not only benefit from RWHS but also to serve as a model of sustainable water management practices. Future research should address the current limitations by conducting comparative assessments of different RWHS types, evaluating their long-term performance, and identifying effective governance and maintenance strategies. In addition, universities also should provide detailed insights into the implementation, operation, and long-term impacts of RWHS in higher education environments, ensuring that the outcomes contribute meaningfully to local sustainability efforts and global water security goals.

Acknowledgements: This article is the result of a research project funded under the Strategic Research Grant, Integrated Framework for Environmental Sustainable Campus (Project Code: KRA-2023-002). The authors would like to express their appreciation to Universiti Kebangsaan Malaysia for supporting this research through the grant. Gratitude is also extended to all researchers who contributed to the completion of this article.

Conflict of Interest: All authors declare that they have no conflict of interest.

References

Abuelfutouh, N. A. K., Jami, M. S., Abdurahman, N. H., Fuad, N. I. M. (2020). Rainwater harvesting quality assessment and evaluation: IIUM case study. *IIUM Engineering Journal*, *21*(1), 12-22. https://doi.org/10.31436/iiumej.v21i1.1139

Afifi, M., Stryhn, H., & Sanchez, J. (2023). Data extraction and comparison for complex systematic reviews: A step-by-step guideline and an implementation example using open-source software. *Systematic Reviews*, *12*, Article 226. https://doi.org/10.1186/s13643-023-02322-1

Ahmed, A., Valyrakis, M., Ghumman, A. R., Arshad, M., Pasha, G. A., Farooq, R., & Janjua, S. (2022). Assessing the rainfall water harvesting potential using Geographical Information Systems (GIS). *CivilEng*, *3*(4), 895-908. https://doi.org/10.3390/civileng3040051

Ali, N. B., & Usman, M. (2019). A critical appraisal tool for systematic literature reviews in software engineering. *Information and Software Technology*, *112*, 48-50. https://doi.org/10.1016/j.infsof.2019.04.006

Amos, C. C., Rahman, A., & Gathenya, J. M. (2016). Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya. *Water*, *8*(4), Article 149. https://doi.org/10.3390/w8040149

Anchan, S. S., & Prasad, H. C. S. (2021). Feasibility of roof top rainwater harvesting potential - A case study of South Indian University. *Cleaner Engineering and Technology*, *4*, Article 100206. https://doi.org/10.1016/j.clet.2021.100206

Aregarot, P., Kubaha, K., & Chiarakorn, S. (2024). A study of sustainability concepts for developing green universities in Thailand. *Sustainability*, *16*(7), Article 2892. https://doi.org/10.3390/su16072892

Augustine, E. E., & Hanafiah, M. M. (2019). Awareness level of water resource conservation of university students. *Water Conservation and Management*, *3*(2), 18-21. https://doi.org/10.26480/wcm.02.2019.18.21

Azmi, E., Rose, R. A. C., Awang, A., & Abas, A. (2023). Innovative and competitive: A systematic literature review on new tourism destinations and products for tourism supply. *Sustainability*, *15*(2), Article 1187. https://doi.org/10.3390/su15021187

Azmi, W. N. A. W. N., Wahid, N. H. A., Azman, S. M. S., & Jayus, R. (2024). Integrating sustainability into curricula: A systematic review of education for sustainable development. *E-Bangi: Journal of Social Sciences and Humanities*, *21*(4), 103-119. https://doi.org/10.17576/ebangi.2024.2104.09

Bateni, N., Fathil, N. S. M., Bustami, R. A., Lai, S. H., Mannan, M. A., & Mah, D. Y. S. (2022). Environmental assessment of stormpav green pavement for stormwater management. *Journal of Sustainability Science and Management*, *17*(6), 182-192. http://doi.org/10.46754/jssm.2022.06.014

Bouzidi, A. E., Anouar, A., & Bouzziri, M. (2024). Management and valuation of rainwater by alternative techniques, case of the University of Settat, in Morocco. *Water Cycle*, *5*, 109-120. https://doi.org/10.1016/j.watcyc.2024.03.001

Cardoso, R. N. C., Blanco, C. J. C., & Duarte, J. M. (2020). Technical and financial feasibility of rainwater harvesting systems in public buildings in Amazon, Brazil. *Journal of Cleaner Production*, *260*, Article 121054. https://doi.org/10.1016/j.jclepro.2020.121054

Che-Ani, A. I., Shaari, A., Zain, M. F. M., & Tahir, M. M. (2009). Rainwater harvesting as an alternative water supply in the future. *European Journal of Scientific Research*, *34*(1), 132-140.

Da Silva, M. B. M., De Paiva Brandão, I. A., & Ribeiro, M. M. R. (2022). Feasibility, seasonality and reliability of rainwater harvesting in buildings of a university in Campina Grande, Paraíba. *Brazilian Journal of Water Resources*, *27*, Article e17. https://doi.org/10.1590/2318-0331.272220210127

Dake, C., Shengyi, Q., & Yuming, S. U. (2021). Enhancing rainwater harvesting through pervious pavement system based on the principle of surface free energy. *Civil Engineering and Urban Planning: An International Journal*, *8*(3), 11-18. https://www.airccse.com/civej/papers/8321civej02.pdf

Dawodu, A., Dai, H., Zou, T., Zhou, H., Lian, W., Oladejo, W., & Osebor, F. (2022). Campus sustainability research: Indicators and dimensions to consider for the design and assessment of a sustainable campus. *Heliyon*, *8*(12), Article e11864. https://doi.org/10.1016/j.heliyon.2022.e11864

Domingos, J. M. F., Marques, D. G., Campos, V., & Nolasco, M. A. (2024). Analysis of the water indicators in the UI Greenmetric applied to environmental performance in a university in Brazil. *Sustainability*, *16*(20), Article 9014. https://doi.org/10.3390/su16209014

Filho, J. V., Scortegagna, A., de Sousa Dias Vieira, A. P., Jaskowiak, P. A. (2024). Machine learning for water demand forecasting: Case study in a Brazilian coastal city. *Water Practice & Technology*, *19*(5), 1586-1602. https://doi.org/10.2166/wpt.2024.096

Garg, V., Bansal, A. K., & Dubey, M. K. (2022). Design of rain water harvesting structure for engineering block. *Ecological Engineering & Environmental Technology*, *23*(1), 261–266. https://doi.org/10.12912/27197050/143383

Goh, S. F., Che-Ani, A. I., Shaari, N., Mohd-Zain, M.F., & Surat, M. (2008). Traditional rainwater system to modern usage: A practical approach. *2nd International Conference on Built Environment in Developing Countries, Pulau Pinang*, 576-587. http://eprints.usm.my/id/eprint/34460

Goh, Y. C., & Ideris, M. (2021). Tangki NAHRIM 2.0: An R-based water balance model for rainwater harvesting tank sizing application. *Water Practice & Technology*, *16*(1), 182-195. https://doi.org/10.2166/wpt.2020.106

Hosseini, M. S., Jahanshahlou, F., Akbarzadeh, M. A., Zarei, M., & Vaez-Gharamaleki, Y. (2024). Formulating research questions for evidence-based studies. *Journal of Medicine, Surgery, and Public Health*, *2*, Article 100046. https://doi.org/10.1016/j.glmedi.2023.100046

Hunt, D. V. L., & Shahab, Z. (2021). Sustainable water use practices: understanding and awareness of masters level students. *Sustainability*, *13*(19), Article 10499. https://doi.org/10.3390/su131910499

Institute for Educational Research and Publication. (2022, April 28). Scopus vs Web of science journal; Which one is better. *Institute for Educational Research and Publication*. https://www.iferp.in/blog/2022/04/28/scopus-vs-web-of-science-journal-which-one-is-better

Jalil, R. A., Sakke, N., & Jafar, A. (2024). Penggunaan, cabaran, dan hala tuju sistem penuaian hujan (SPAH): Satu penelitian awal. *E-Bangi: Journal of Social Sciences and Humanities*, *12*(4), 164-175. https://doi.org/10.17576/ebangi.2024.2104.14

Jian, Z., Kumar, M., & Werner, D. (2021). Real-world sustainability analysis of an innovative decentralized water system with rainwater harvesting and wastewater reclamation. *Journal of Environmental Management*, *280*, Article 111639. https://doi.org/10.1016/j.jenvman.2020.111639

Kapli, F. W. A., Azis, F. A., Suhaimi, H., Shamsuddin, N., & Abas, P. E. (2023). Feasibility studies of rainwater harvesting system for ablution purposes. *Water*, *15*(9), Article 1686. https://doi.org/10.3390/w15091686

Kiger, M. E., & Varpio, L. (2020). Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical Teacher*, *42*(8), 846–854. https://doi.org/10.1080/0142159X.2020.1755030

Kolaski, K., Logan, L. R., & Ioannidis, J. P. A. (2023). Guidance to best tools and practices for systematic reviews. *Systematic Reviews*, *12*(96). https://doi.org/10.1186/s13643-023-02255-9

Kolavani, N. J., & Kolavani, N. J. (2020). Technical feasibility analysis of rainwater harvesting system implementation for domestic use. *Sustainable Cities and Society*, *62*, Article 102340. https://doi.org/10.1016/j.scs.2020.102340

Kumar, V., Mukwana, K. C., Jatoi, A. R., Hassan, M., Jakhrani, A. Q., Siyal, A. A., Zaman, K. U., & Kumar, L. (2022). GIS-based analysis of a rainwater harvesting system in the multipurpose hall of Quaid-e-Awam University of Engineering, Science, and Technology. *Engineering, Technology & Applied Science Research*, *12*(4), 8837-8842. https://doi.org/10.48084/etasr.4995

Lani, N. H. M., Yusop, Z., & Syafiuddin, A. (2018). A review of rainwater harvesting in Malaysia: Prospects and challenges. *Water*, *10*(4), Article 506. https://doi.org/10.3390/w10040506

Mostaffa, M. F., Musa, S. M. S., Zainal, R., Kasim, N., Noh, H. M., & Yassin, A. M. (2021). E-SPAH: Aesthetic innovation in UTHM's small-scale rainwater harvesting system. *International Journal of Integrated Engineering*, *13*(5), 239-246. https://doi.org/10.30880/ijie.2021.13.05.025

Muchadeyi, M. T., Hernandez-Villafuerte, K., Di Tanna, G. L., Eckford, R. D., Feng, Y., Meregaglia, M., Peasgood, T., Petrou, S., Ubels, J., & Schlander, M. (2024). Quality appraisal in systematic literature reviews of studies eliciting health state utility values: Conceptual considerations. *PharmacoEconomics*, *42*, 767-782. https://doi.org/10.1007/s40273-024-01365-z

Muhiddin, A. A. M., Isa, H. M., Sakip, S. R. M., Nor, O. M., & Sedhu, D. S. (2023). Green campus implementation in the Malaysian public universities: Challenges and solutions. *Planning Malaysia Journal*, *21*(1), 274-298. https://doi.org/10.21837/pm.v21i25.1239

Musa, S. M. S., Mostaffa, M. F., Manap, N., Yassin, A. M., & Zainal, R. (2022). Small scale rainwater harvesting design for external usage. *Environment and Ecology Research*, *10*(2), 267-274. https://doi.org/10.13189/eer.2022.100216

Naeem, M., Ozuem, W., Howell, K., & Ranfagni, S. (2023). A step-by-step process of thematic analysis to develop a conceptual model in qualitative research. *International Journal of Qualitative Methods*, *22*. https://doi.org/10.1177/16094069231205789

Oberascher, M., Kinzel, C., Kastlunger, U., Schöpf, M., Grimm, K., Plaiasu, D., Rauch, W., & Sitzenfrei, R. (2022). Smart water campus – a testbed for smart water applications. *Water Science & Technology*, *86*(11), 2834-2847. https://doi.org/10.2166/wst.2022.369

Raimondi, A., Quinn, R., Abhijith, G. R., Becciu, G., & Ostfeld, A. (2023). Rainwater harvesting and treatment: State of the art and perspectives. *Water*, *15*(8), Article 1518. https://doi.org/10.3390/w15081518

Rainharvesting Systems. (2023). Types of rainwater harvesting systems. *Rainharvesting Systems*. https://rainharvesting.co.uk/types-of-rainwater-harvesting-systems/

Richards, S., Rao, L., Connelly, S., Raj, A., Raveendran, L., Shirin, S., Jamwal, P., & Helliwell, R. (2021). Sustainable water resources through harvesting rainwater and the effectiveness of a low-cost water treatment. *Journal of Environmental Management*, *286*, Article 112223. https://doi.org/10.1016/j.jenvman.2021.112223

Richardson, J. (2024, September 4). History of rainwater harvesting. *The Renewable Energy Hub*. https://www.renewableenergyhub.co.uk/main/rainwater-harvesting-information/history-of-rainwater-harvesting

Samzadeh, M., Din, N. C., Abdullah, Z., Mahyuddin, N., & Ismail, M. A. (2021). Feasibility of vertical rainwater harvesting via in-situ measurement of wind-driven rain loads on building facades in a tropical climate. *International Journal of Built Environment and Sustainability*, *8*(3), 27-45. https://doi.org/10.11113/ijbes.v8.n3.736

Scopus. (n.d.). *Start exploring*. Retrieved June 9, 2024, from https://www.scopus.com/pages/home

Shaffril, H. A. M. (2020). *Metodologi asas systematic literature review*. Hayrol Azril Mohamed Shaffril.

Soni, P., Medhi, H., Sagar, A., Garg, P., Singh, P., & Karna, U. (2022). Runoff estimation using digital image processing for residential areas. *Aqua: Water Infrastructure, Ecosystems and Society*, *71*(8), 938-948. https://doi.org/10.2166/aqua.2022.070

Sultana, S. (n.d.). Advantages and disadvantages of rainwater harvesting. *Civil Engineering*. https://civiltoday.com/water-resource-engineering/irrigation/412-advantages-and-disadvantages-of-rainwater-harvesting

Suni, S., Firdaous, M. H., Zailani, F. F., Gödeke, S., Mohd Raffi, R., & Abas, P. E. (2025). Urban water management and public acceptance of rainwater harvesting systems: Insights from young and educated respondents in Muslim communities. *Sustainability*, *17*(7), Article 3046. https://doi.org/10.3390/su17073046

Teston, A., Piccinini Scolaro, T., Kuntz Maykot, J., & Ghisi, E. (2022). Comprehensive environmental assessment of rainwater harvesting systems: A literature review. *Water*, *14*(17), Article 2716. https://doi.org/10.3390/w14172716

Trifu, A., Smîdu, E., Badea, D. O., Bulboacă, E., & Haralambie, V. (2022). Applying the PRISMA method for obtaining systematic reviews of occupational safety issues in literature search. *10th International Symposium on Occupational Health and Safety*, *MATEC Web of Conferences*, *354*(00052), 1-8. https://doi.org/10.1051/matecconf/202235400052

University of South Australia. (n.d.). Systematic reviews. *University of South Australia*. https://guides.library.unisa.edu.au/SystematicReviews

Vaz, I. C. M., Ghisi, E., & Thives, L. P. (2021). Stormwater harvested from permeable pavements as a means to save potable water in buildings. *Water*, *13*(14), Article 1896. https://doi.org/10.3390/w13141896

Web of Science. (n.d.). *Your trusted path to discovery*. Retrieved June 9, 2024, from https://www.webofscience.com/wos/woscc/smart-search

Xu W. D., Fletcher, T. D., Burns, M. J., & Cherqui, B. F. (2020). Real time control of rainwater harvesting systems: The benefits of increasing rainfall forecast window. *Water Resources Research*, *56*(9), Article e2020WR027856. https://doi.org/10.1029/2020WR027856

Yoo, C., Cho, E., Lee, M., & Kim, S. (2022). Observation experiment of wind-driven rain harvesting from a building wall. *Water*, *14*(4), Article 603. https://doi.org/10.3390/w14040603