Rainwater Quality Disparities Across Malaysian Peninsula Sites

Md. Helal Uddin[1,2,*], Md. Rokonuzzaman[1], Mohammad Nur-E-Alam[1], Manzoore Elahi M. Soudagar[3,4], Hassan bin Mohamed[1,2] and Nowshad Amin[5]

[1]*Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional (UNITEN), Kajang 43000, Selangor, Malaysia*
[2]*Department of Mechanical Engineering, Collage of Engineering, Universiti of Tenaga Nasional, Jalan-Ikram, UNITEN, 43000, Kajang, Selangor, Malaysia*
[3]*Faculty of Engineering, Lishui University, 323000, Lishui, Zhejiang, People's Republic of China*
[4]*Department of Mechanical Engineering and University Centre for Research & Development, Chandigarh University, Mohali 140413, Punjab, India*
[5]*Department of Electrical and Electronic Engineering, Faculty of Engineering, American International University-Bangladesh, 408/1, Kuratoli, Dhaka 1229, Bangladesh*
E-mail: mdhelaluddinarnob@gmail.com
[*]*Corresponding Author*

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Abstract

This research describes the physicochemical quality of harvested rainwater at four distinct locations in Peninsula Malaysia. The evaluation of rainwater quality across different geographic areas aims to provide valuable insights into potential variations and trends in rainwater quality to reduce water demand globally. This analysis is conducted to determine seven properties, namely ammoniacal nitrogen, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), dissolved oxygen (DO), pH, total dissolved solids (TDS), and turbidity. The results demonstrate that the quality of harvested

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rainwater meets the raw water quality standards set by the World Health Organization (WHO) and the National Water Quality Standards for Malaysia (NWQSM), indicating good quality rainwater in Malaysia. However, the COD for rainwater in all locations exceeded the limit, with a range of 14.1 to 29.7 mg/L, while the maximum limit for COD set by WHO is 10 mg/L, and according to NWQSM standards, it is 10–100 mg/L. The average pH of the collected rainwater is acidic ranged from 4.7 to 5.56. BOD_5 for the collected rainwater is excellent; however, L2 has a slightly higher BOD_5 at 6.5 mg/L, whereas the recommended limit by WHO is 6 mg/L, and the NWQSM standard suggests a range of 1–12 mg/L, with a standard limit of 5–7 mg/L. Nevertheless, DO levels ranged from 7.71 to 7.76 mg/L, indicating an ambient gas concentration in the rainwater. The collected rainwater can be used for portable purposes, gardening, smart farming, and toilet flushing.

Keywords: Rainwater harvesting, rainwater quality, raw water, sustainable water resource, pollutant-free rainwater.

1 Introduction

Climate change has disrupted water availability and quality, leading to floods and droughts. To combat these challenges, rainwater harvesting is increasingly vital. This practice reduces strain on traditional water sources, minimizes urban flood risks, and safeguards aquatic ecosystems, contributing to sustainable water management. Several research works have focused on the importance of rainwater collection and harvesting in many ways and investigated the potential to increase groundwater levels and to use it as an integrated water source in drought areas [1–3]. In addition, it aids in replenishing vital underground and surface water sources. Rainwater harvesting is primarily employed for non-drinking purposes, encompassing municipal applications like street and square irrigation, gardening, sanitation, sewer system flushing, industrial functions (e.g. technological processes, fire water provision, and cleaning), agricultural activities (including crop cultivation, irrigation, livestock care, and agricultural production), household usage (e.g. gardening, watering, toilet flushing, laundry, car washing, and cleaning), as well as in commercial areas, sports facilities, airports, etc., for purposes like toilet flushing, fire protection, and cleaning [4]. The benefits and hazards of using rainwater as a substitute for other drinking water sources must be determined, for instance by considering factors related to health and hygiene, the environment, economics, public awareness, and reliability [5]. Water is one of the essential needs in human life. Every day, we need a clean and safe water supply to do our daily routine, especially for drinking. However, due to excessive industrialization growth, water quality is highly affected. Surface water, such as streams, ponds, and lakes, contains high turbidity. The complication of drinking water is a significant issue worldwide; the expanding complex interaction of competing water demands and the provision of high-quality water is not complex [6]. Rainwater harvesting is an age-old practice that has resurfaced in demand due to the natural purity of rainwater and a desire to reduce the need for treated water. It is a technique where the rainfall is collected and gathered using different methods and stored for daily activities. These techniques can potentially solve current water demand problems [7]. In many regions of the world, groundwater levels have drastically decreased in recent decades as a result of human activity and climate change. The study focuses on the environmental effects and long-term possibilities of rooftop rainwater harvesting in conjunction with shallow well penetration, which is an affordable local solution that may help alleviate water scarcity [8]. According to the United Nations, approximately 1.2 billion human beings barely have a pure drinking water supply. In 2050, the demand for water supply will increase to 50% compared to the amount presently consumed to supply nine billion people [7, 9]. In Malaysia, surface water resources such as rivers and reservoirs account for more than 98% of current water usage. Groundwater contributes to less than 2% of recent water usage. As a result, most of the country's water is utilized for agriculture, industry, and home needs. Anang, 2019, acknowledged that many characteristics are involved in water demand; agriculture and farming require significant water usage. Climate variability has an impact on water resources as well.

Furthermore, the author mentioned that water is a source of productivity, and as the world's population grows, so does the water demand, putting further strain on water supplies [10]. Lani and Nor, 2018, reported that the variation in the climate is expected to reduce rainfall in some Malaysian states. Malaysia is one of the countries with high household water usage, with daily intake ranging from 209 to 228 liters per capita (LCD) despite Malaysia's water tariff being relatively affordable compared to other wealthy countries, In Johor [11]. The requirements for water quality and prospective usage are two crucial factors that must be considered when dealing with rainwater applications. The water's possible applications, especially when examining potential health hazards, are typically considered while determining the quality requirements. This implies that depending on the intended application, a particular water source will need a particular level of treatment.

Therefore, it is crucial to understand the initial quality of each water resource to assess possible applications, choose the right storage option, and establish the necessary amount of treatment. The ongoing study focuses on rainwater gathering and its quality because it is crucial to a sustainable future, primarily. For example, research by Yaziz [12] concluded that there was a significant difference in the pollutant content between the water samples taken from the tile roof and the galvanized iron roof when total and faecal coliform were considered.

Furthermore, it was discovered that the concentration of several pollutants was lower in the latter rainfall spill than the earlier rainfall spill. Jiries [13] during the period of little rainfall, it was established the metallic content and inorganic constituent were identified. However, high levels of copper and lead were found, which may be related to road pollution. Teemusk and Mander, 2007, reported that the quality of rainwater discovered a connection between rainwater quality and rainfall intensity. In samples obtained during a moderate downpour, the component was found to be more concentrated because the rain washed the contamination away, but in samples taken after a strong downpour, the component was found to be less concentrated [14]. According to other studies, the location of the sampling station, and industrial, urban, or agricultural activity significantly affect the chemical composition of rainwater collected. According to Zunckel, 2003, [15], there is a significant correlation between the quality of rainfall and contaminants in the catchment region. The key contributors to the link between nitrate and ammonium in that area are trees, cattle, and fertilizer. This study aims to find the untreated raw water quality in peninsula Malaysia to compare with the standard set by WHO and NWQSM to ensure quality of the harvested-rainwater for various purposes in daily life and reduce the pressure on the nation's ground water.

2 Methods

2.1 Study Area

The focal point of this research study centers around the Selangor state (namely, location 1 (L1), location 2 (L2), location 3 (L3), and location 4 (L4), in Selangor state), strategically situated in the heart of Peninsular Malaysia along its western coastline. Enveloping the Federal Territory of Kuala Lumpur and Putrajaya, Selangor's geographical significance is undeniable. The state's terrain is characterized by a level expanse to the west, gradually transitioning into hilly landscapes toward the east. The convergence

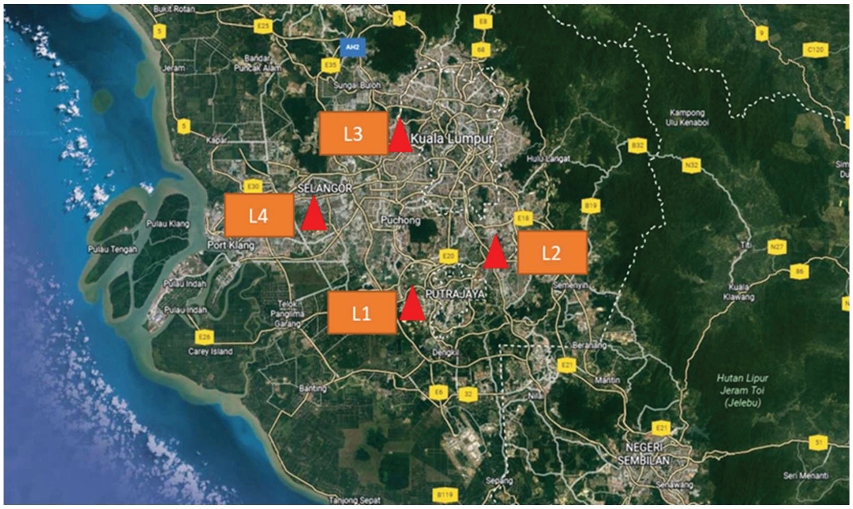

Figure 1 Satellite view of the locations from.

Table 1 Sample collecting areas

Place	Environment Type	Locations	Sample Name
UNITEN	University area	College of Engineering, BL	L1
Cyberjaya	Residential area	Kanvas Soho Condominium	L2
Sah Alam	Industrial area	HICOM Industrial Estate	L3
Kuala Lampur	City Centre	Universiti Malaya	L4

of hills and mountains on the state's western fringe shapes a distinctive valley and basin formation. This natural contour cradles the Klang River, locally called Sungai Klang. This geographical feature has culminated in the well-known Klang Valley, emerging as the epicenter of the state's most densely populated areas. The research method was carried out through rainwater sample collection at four strategically chosen points within Selangor and Kuala Lumpur, as meticulously detailed in Figure 1.

2.2 Sample Collecting Areas and Location and Environment Type

These locations were thoughtfully selected to encompass a diverse range of atmospheric conditions. They encompass the university area, a residential housing estate, an industrial estate replete with factories and manufacturing facilities, and the city's heart, each highlighted in Table 1.

This thoughtfully devised approach allows for comprehensive exploration of rainwater quality variation, attributed to factors such as air pollution, windborne particulates, and potentially harmful substances. The research further underscores the intricate interplay between environmental factors and rainwater composition, accentuating the need for a nuanced understanding of the complex dynamics shaping urban and suburban rainwater quality across distinct regions.

2.2.1 University area

Situated atop an expanse 70 meters above sea level, Universiti Tenaga Nasional (UNITEN) occupies an open, elevated terrain. This study is meticulously crafted to delve into the intricacies of rainwater quality within the confines of the University's premises. The distinctiveness of UNITEN's location comes to the forefront, characterized by its intentional distance from both industrial zones and city centres. A key facet contributing to the uniqueness of this study site is its deliberate separation from residential localities. UNITEN's campus design embodies sustainability and green principles, rendering it an embodiment of ecologically mindful practices. This distinct setting, portrayed eloquently in Figure 2(a), underpins the research's central focus on assessing rainwater quality within a self-contained and environmentally conscious space. Rainwater samples were diligently collected within the confines of the College of Engineering department, serving as a representative site within the campus. This specific site was chosen to provide a comprehensive overview of rainwater quality within the context of academic and research activities. The methodological precision in sampling further underscores the scientific rigor underlying the study's objectives.

2.2.2 Residential area

Kanvas Soho Condominium is 20 m above sea level, situated within a residential enclave, this area enjoys the advantage of reduced air pollution owing to its distance from industrial zones and city centres. As a result of this favourable positioning, the quality of rainwater in this locale is anticipated to be of superior condition when juxtaposed with other environments. The harmonious interplay between the residential setting and its relatively pristine air quality is eloquently depicted in Figure 2(b). This visual representation accentuates the premise that a tranquil residential area can yield remarkable amounts of rainwater, further emphasizing the importance of considering various environmental factors in rainwater quality assessments.

2.2.3 Industrial area

The Shah Alam industrial area, situated at an elevation of 18 meters above sea level, has been selected for comprehensive rainwater quality analysis. This selection stems from the concerning rise in air pollution caused by heavy metals and gases within the vicinity. The influence of these substances substantially impacts the atmospheric conditions and the composition of rainwater. The specific purpose behind opting for this distinct locale is to delve into the intricate dynamics of how air pollution is intricately linked to alterations in rainwater quality. This pursuit is elegantly illustrated in the Figure 2(c), underscoring the significance of understanding these interconnections for a more comprehensive environmental perspective.

2.2.4 City centre

Perched at an elevation of 100 meters above sea level, Universiti Malaya in Kuala Lumpur is our study's focal point. Situated within the bustling city center, particularly in Kuala Lumpur, this area experiences a significant surge in traffic volume. The vehicular activity within the city releases substantial amounts of carbon dioxide, a greenhouse gas known for its prevalence in urban environments. In contrast to the other three locations under scrutiny, this concentration of carbon dioxide is notably heightened. The pervasive presence of this greenhouse gas, emitted primarily from vehicles, holds the potential to exert a discernible influence on rainwater quality. The intricate interplay between vehicular emissions and atmospheric conditions culminates in an altered chemical composition of rainwater, ultimately affecting its quality and characteristics. These dynamics are briefly illustrated in the accompanying technical Figure 2(d). The diagram serves as an informative visual representation of how the interaction between urban traffic emissions and rainwater quality underscores the need for meticulous analysis to comprehend the multifaceted impact of urban.

2.3 Rainwater Collecting Buckets

Rainwater was collected directly from the sky without encountering any catchment surfaces. White-colored buckets are employed for visual monitoring of rainwater quality during collection. Before positioning the buckets for collection, thorough cleaning is imperative to eliminate dust, dirt, or microorganisms from within them, ensuring their pristine condition. Consequently, the buckets underwent a meticulous cleaning process. They were initially washed with soapy water and subsequently dried using lint-free tissues.

Figure 2 Rainwater collection at, a) L1; b) L2; c) L3 and d) L4.

Subsequently, a thorough cleaning was performed using alcohol, repeating the process three times. Following the 30% methanol (v/v) cleaning, the buckets were further cleansed using deionized water (DI) greatly and dried using lint-free tissue. The next step involved labeling the buckets based on their designated locations. Once labeled, the buckets were strategically positioned for rainwater harvesting, as depicted in Figure 3.

2.4 Harvesting Rainwater

Each stage in the process of collecting rainwater must be properly regulated. The bucket's lid was left open during a downpour to collect water. When the rain stopped, the lid was quickly closed to ensure the water's purity and avoid contamination by preventing any dirt or ants from falling into it.

3 Results and Discussion

This study investigates untreated rainwater quality for NH3-N, BOD_5, COD, DO, TDS, pH, and turbidity parameters to differentiate rainwater quality.

Figure 3 Cleaning of rainwater harvesting buckets.

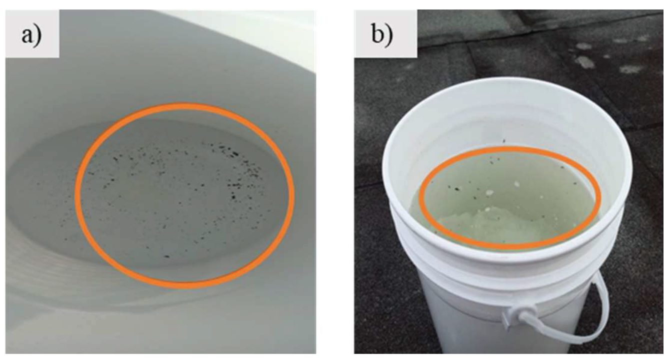

Figure 4 Rainwater collection, a) Initial stage; b) Final stage.

Based on the observation, at the beginning the collection of rain was very little in amount however, due to the ongoing heavy rainfall, a significant amount rainwater was collected. The rainwater collected from different locations has pollutants from animal waste, birds, and dust particles. Chemical pollutants from emissions yielded by the combustion process of fuel from automobiles and industries. Microbiological contaminants come from viruses and bacteria found in the air, as shown in Figures 4(a) and 4(b).

The collected rainwater data for and the WHO standard and National Water Quality Standards for Malaysia for raw water quality are presented in the Tables 2 and 3, respectively.

Table 2 Rainwater parameters for different locations

Parameters	Units	L1	L2	L3	L4
NH3-N	(mg/L)	0.0764	0.0872	0.0886	0.0444
pH	(at 25°C)	4.7000	5.1500	5.5600	4.9400
Turbidity	(NTU)	0.4800	0.7300	0.8700	0.5600

Table 3 WHO standard and National Water Quality Standards for raw water quality in Malaysia [16, 17]

Parameters	Units	WHO	NWQSM
NH3-N	(mg/L)	1.5000	0.1–2.700
BOD_5	(mg/L)	6.0000	1.0–12.00
COD	(mg/L)	10.000	10.00–100
DO	(mg/L)	–	5.00–7.00
TDS	(mg/L)	1500.0	500–4000
pH	(at 25°C)	5.5–9.0	5.00–9.00
Turbidity	(NTU)	1000.0	5.00–50.0

3.1 Ammoniacal Nitrogen (NH3-N)

The lowest value of NH3-N was obtained at L4, which was 0.0444 mg/L and the greatest value obtained 0.0886 mg/L at L3. The value obtained for all the locations is smaller than the 1.5 mg/L standard set by the WHO and 2.7 mg/L according to NWQSM. The fluctuations in the values are caused by various factors such as the amount of rainfall, proximity to trees, and environmental dust [18].

3.2 Biological Oxygen Demand (BOD_5)

Figure 5 illustrates the concentration of BOD_5, COD, DO, and TDS of rainwater harvested in the research. Biological oxygen demand measures the quantity of oxygen required for aerobic microorganisms to decompose waste organic matter in water [18]. Figure 5 illustrates the concentration of BOD_5 in harvested rainwater. The value for BOD_5 for all the locations is in the range. However, L2 exceeded the limit for BOD_5 set by WHO, indicates a higher organic pollutant concentration, potentially compromising water quality for various uses. Remedial actions such as improved wastewater treatment or stricter regulatory controls are necessary to mitigate health and environmental risks associated with contaminated water. However, following the NWQSM standard, the highest BOD_5 limit is 12 mg/L. The lowest BOD_5 value obtained at L4 which is 2.6 mg/L. The highest value obtained 6.5

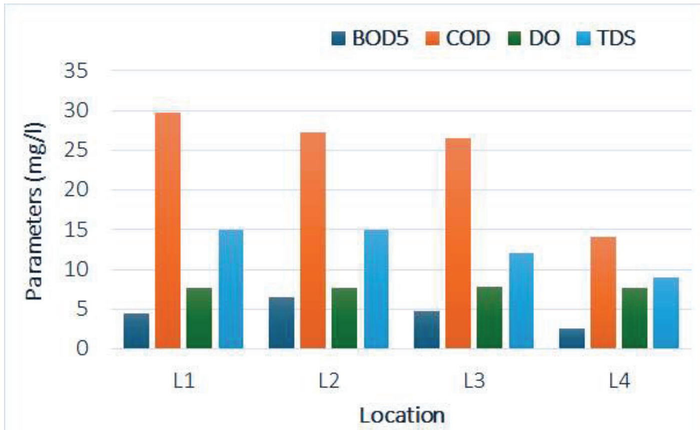

Figure 5 BOD_5, COD, DO, and TDS values at different locations for unfiltered rainwater.

mg/L at L2. Indicating that residential area has higher BOD_5 means more oxygen is required, which means it is less for oxygen-demanding organisms to consume and worse water quality. On the flip side, Low BOD_5 signifies less oxygen is lost from the water, producing it purer [19]. An industrial area has a low BOD_5 defining, the water contains few organic matters and few microbial species. BOD_5 may measure the size of biological treatment facilities and aeration in ponds [20]. In general industrial activities often discharge higher organic loads into water sources, contributing to elevated BOD_5 levels compared to the residential area. However, our experimentally found data indicated that the BOD_5 concentration level is slightly higher than that of industrial areas, which could be one reason that the selected residential area (L2) is very near to many high-rise buildings, hospitals, educational institutions, railway stations and a couple of very busy free-ways and highly elevated high-ways.

3.3 Chemical Oxygen Demand (COD)

All the achieve values are greater than 10 mg/L, the maximum limit of raw water quality by WHO. The greatest value obtained is 29.7 mg/L at L1 and the smallest 14.1 mg/L at L4. Despite that, the raw water standard NWQSM set the highest COD limit is 100 mg/L. The oxygen equal to the organic matter in a water specimen susceptible to oxidation by a powerful chemical oxidant is calculated by COD. COD is a typically used metric for defining the vulnerability of organic and inorganic components in water bodies and municipal and factory wastes to oxidation. The COD test of natural water determines the total oxygen required to oxidize waste to carbon dioxide and water [21]. Elevated levels of COD in rainwater demonstrate organic concentrations in the water and lead from motor vehicles carried by wind and dissolved with rain. The rainwater quality for COD is comparatively high. Treatment should be carried out to escalate the usage of rainwater as raw water [18].

3.4 Dissolved Oxygen (DO)

Dissolved oxygen (DO) is the amount of oxygen in the water. Water bodies receive oxygen from the air and aquatic plants [22]. Rainwater immerses carbon dioxide, oxygen, nitrogen dioxide, and sulphur dioxide in the atmosphere [23]. The graph 8 shows the amount of DO in the rainwater compared to different locations. The highest DO values were measured at 7.76 mg/L at L3, the rest of the obtained values are constant over locations of 7.71 mg/L. The DO values are slightly higher 7 mg/L, the maximum limit of raw water quality by NWQSM. The dissolved oxygen (DO) in rainwater is primarily derived from the atmosphere. The concentration of DO in the atmosphere is generally higher than in water bodies, as atmospheric oxygen is constantly replenished through various natural processes, such as photosynthesis by plants and algae [23].

3.5 Total Dissolved Solids (TDS)

Total Dissolved Solids in rainwater result from natural environmental elements, namely salt-carbonate deposits that occur on the roof. The contaminants including dust, animal feces, and leaves can cause salt to be deposited on roofs. Airborne contaminants like sulphur and nitrogen oxide can liquefy with the rainwater [18]. The maximum value obtains 15 mg/L while the minimum is 9 mg/L. The recommended raw water quality for TDS is 1500 mg/L by WHO and 4000 mg/L by NWQSM. The obtained values are under the range, indicating obtained values are normal. The difference in the TDS values among the locations illustrates that the university and residential areas have more pollutants than the city centre and industrial areas, respectively.

3.6 pH

A substance's pH is the magnitude of electrically charged particles. It signifies the material is acidic or alkaline [24]. The average pH value of the all the locations were in between 4.7 to 5.56 which is below neutral value 7. The lowest value obtained at L1, 4.7. That indicating acidic rain in the sample collecting areas. It can be observed from the figure 10 that rainwater is slightly be observed from the figure 10 that rainwater is slightly acidic due to the CO_2 in the air and the emission of gasses from the motor vehicle. The pH fluctuation also occurred as collected rainwater mixed in with leaves, dust, and bird dung. The pH variation is identified due to the deposition of atmospheric particulate matter [18]. The recommendation of pH is in the range of 5.5–9 by WHO and 5–9 by NWQSM as lower pH is corrosive which may negatively impact vehicle washing, and agricultural usage, harmful to fish and wildlife [16].

3.7 Turbidity

The lowest 0.48 NTU was observed at L1 while the highest at L4, 0.87 NTU. All the measurements for turbidity are below the value of 1000 NTU, which is WHO raw water quality standard, and 50 NTU by NWQSM. Turbidity in rainwater is generated by suspended solids substances, either inorganic or organic. The heightened turbidity indicates that rainwater has been contaminated physically, chemically, and biologically [25]. Turbidity is the cloudiness or haziness of a fluid determined by immense numbers of individual particles. Turbidity causes the water to become cloudy [26].

4 Technology, Integration, and Regulatory Challenges

Rainwater harvesting systems have been changed during the past ten years by technological developments in materials science and filtering technologies. The effectiveness and durability of filtration systems have been greatly improved by innovations like the construction of distinctive rainwater collection tanks using conventional techniques and the incorporation of nanoparticles and smart composites. By successfully eliminating impurities, the application of membrane filtration technologies and nanofilters has enhanced water quality. Additionally, the integration of automated systems and smart sensors allows for the real-time administration and monitoring of water quality and levels, which optimizes the entire process of collection and distribution. These developments have improved rainwater collecting systems' longevity and dependability while also lowering their cost of adoption and facilitating wider use, supporting sustainable water management techniques around the world [27–30]. Integrating rainwater harvesting systems into urban infrastructure requires engineering challenges that can be addressed through innovative solutions. Compact, multi-functional designs are crucial due to limited space in buildings, necessitating creative solutions to fit storage tanks within existing structures or underground spaces. Retrofitting drainage systems to collect rainwater without compromising flood management requires meticulous planning and potentially new infrastructure designs. Adapting roads and pavements with permeable surfaces or green infrastructure can aid rainwater infiltration and reduce runoff. Effective integration of rainwater harvesting systems into urban environments demands coordination among urban planners, architects, and engineers to overcome these challenges [31–34]. The legislative frameworks in Malaysia, such as the Malaysian Uniform Building By-Laws (UBBL) 1984, which was revised in 2012 to require rainwater harvesting systems in new buildings, provide guidelines for the implementation of these systems. Water quality requirements and storage tank specifications are just two of the comprehensive rules on system design, installation, and maintenance that are provided by the Malaysian Department of Requirements (MS 2099:2014) [35, 36]. To safeguard water supplies and avoid contamination, large-scale projects must abide by environmental standards and municipal zoning laws. Although these actions support sustainable water management, there are obstacles to overcome, particularly for smaller towns, such as costs and compliance. However, rainwater collection is becoming more and more recognized by Malaysia's legal framework as an essential tactic for sustainable water management [35–39].

5 Conclusion & Future Works

The results of the analyses of the collected rainwater show that within the scope of the tested parameters, such as NH3-N, BOD_5, pH, Turbidity, TDS, the tested rainwater complies with the WHO and NWQSM requirements for raw water standards. According to the analyses carried out, the most significant problem relating to rainwater quality is the high COD presence. This elevation in COD levels may indicate the presence of organic pollutants that require attention. Therefore, it is advisable to consider implementing filtration methods to further improve the quality of harvested rainwater. Implementing filtration methods is recommended to mitigate COD and improve rainwater quality for various applications. Additionally, attention should be given to managing periodic low pH and corrosive properties caused by low alkalinity and aggressive CO_2 levels in harvested rainwater. The colour (Original pH) for all the location was in the range of 5.5–9. One significant issue with the harvested rainwater is the elevated Dissolved Oxygen (DO) levels in rainwater samples, serving as an intriguing indicator of the ambient gas concentrations within the atmospheric milieu. One significant advantage of collecting rainwater directly from the sky, without the need for elaborate harvesting systems, is the assurance of minimal heavy metal contamination. This direct collection method safeguards against heavy metal presence in the water, contributing to the overall safety of rainwater for consumption and usage. To ensure an adequate supply of rainwater for analysis and daily needs, it is recommended to utilize multiple buckets, ideally 4–5, when collecting rainwater. This strategy mitigates the risk of insufficient water supply during periods of inadequate rainfall, ensuring a more consistent and reliable source of rainwater for various applications. While unfiltered rainwater in the Peninsula of Malaysia generally complies with WHO and NWQSM guidelines for raw water quality, there is room for improvement, particularly regarding COD and DO levels. Therefore, the implementation of filtration methods, along with the use of multiple collection buckets which is one of our ongoing research projects, can optimize the utilization of rainwater and thus can ensure a sustainable and reliable water source for multi-purpose uses like as households and agricultural activities all over in Malaysia.

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Author Contribution

M.H.U., M.R., and N.A.: Concept, methodology, investigation, data curation, formal analysis, visualization, validation. M.N-E-A., M.E.M.S, and N.A.: data curation, formal analysis, visualization, validation. M.R., and N.A.: supervision. M.H.U., H.B.M., M.R., M.N-E-A.: writing the review, and editing. All authors have read and agreed to submit this manuscript.

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Data Availability

Data will be provided on request.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Zsóka Szabó, Daniele Pedretti, Marco Masetti, Tibor Ridavits, Endre Csiszár, György Falus, László Palcsu, Judit Mádl-Szőnyi, "Rooftop rainwater harvesting by a shallow well – Impacts and potential from a field experiment in the Danube-Tisza Interfluve, Hungary," Groundwater for Sustainable Development, Vol. 20, 2023, 100884, https://doi.org/10.1016/j.gsd.2022.100884.

[2] Mukund Patil, Moses Shyam Davala, R Santhosh Kumar, Sreenath Dixit, "Investigating the relationship between groundwater augmentation and water quality in the 6000 ha watershed in Telangana state, India," Groundwater for Sustainable Development, Vol. 19, 2022, 100857, https://doi.org/10.1016/j.gsd.2022.100857.

[3] Md. Ferozur Rahaman, Chowdhury S. Jahan, Quamrul H. Mazumder, "Rainwater harvesting: Practiced potential for Integrated Water Resource Management in drought-prone Barind Tract, Bangladesh," Groundwater for Sustainable Development, Vol. 9, 2019, 100267, https://doi.org/10.1016/j.gsd.2019.100267.

[4] K. Mazurkiewicz and J. Je, "Science of the Total Environment Physicochemical and microbiological quality of rainwater harvested in underground retention tanks," vol. 814, 2022, doi: 10.1016/j.scitotenv.2021.152701.

[5] J. Vaze and F. H. S. Chiew, "Experimental study of pollutant accumulation on an urban road surface," *Urban Water*, vol. 4, no. 4, pp. 379–389, Dec. 2002, doi: 10.1016/S1462-0758(02)00027-4.

[6] F. Ahmed, C. Siwar, and R. A. Begum, "Water resources in Malaysia: Issues and challenges," vol. 12, no. April, 2014.

[7] A. Oktaviani and N. Suwartha, "Analysis of multimedia filter effectiveness to improve the quality of rainwater runoff in fulfilling urban raw water supply," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 623, no. 1, 2021, doi: 10.1088/1755-1315/623/1/012008.

[8] Z. Szabó et al., "Rooftop rainwater harvesting by a shallow well – impacts and potential from a field experiment in the Danube-Tisza Interfluve, Hungary," *Groundw. Sustain. Dev.*, vol. 20, no. November 2022, 2023, doi: 10.1016/j.gsd.2022.100884.

[9] R. Shaheed, W. H. M. Wan Mohtar, and A. El-Shafie, "Ensuring water security by utilizing roof-harvested rainwater and lake water treated with a low-cost integrated adsorption-filtration system," *Water Sci. Eng.*, vol. 10, no. 2, pp. 115–124, 2017, doi: 10.1016/j.wse.2017.05.002.

[10] Z. Anang, J. Padli, N. K. Abdul Rashid, R. M. Alipiah, and H. Musa, "Factors affecting water demand: Macro evidence in Malaysia," *J. Ekon. Malaysia*, vol. 53, no. 1, pp. 17–25, 2019, doi: 10.17576/JEM-2019-53 01-2.

[11] N. H. M. Lani, Z. Yusop, and A. Syafiuddin, "A review of rainwater harvesting in Malaysia: Prospects and challenges," *Water (Switzerland)*, vol. 10, no. 4, pp. 1–21, 2018, doi: 10.3390/w10040506.

[12] M. I. Yaziz, H. Gunting, N. Sapari, and A. W. Ghazali, "Variations in rainwater quality from roof catchments," *Water Res.*, vol. 23, no. 6, pp. 761–765, Jun. 1989, doi: 10.1016/0043-1354(89)90211-X.

[13] A. G. Jiries, H. H. Hussein, and Z. Halaseh, "The quality of water and sediments of street runoff in Amman, Jordan," *Hydrol. Process.*, vol. 15, no. 5, pp. 815–824, Apr. 2001, doi: 10.1002/HYP.186.

[14] A. Teemusk and Ü. Mander, "Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events," *Ecol. Eng.*, vol. 30, no. 3, pp. 271–277, Jul. 2007, doi: 10.1016/J.ECOLENG. 2007.01.009.

[15] M. Zunckel, C. Saizar, and J. Zarauz, "Rainwater composition in north-east Uruguay," *Atmos. Environ.*, vol. 37, no. 12, pp. 1601–1611, Apr. 2003, doi: 10.1016/S1352-2310(03)00007-4.

[16] H. Galal-Gorchev, "WHO guidelines for drinking-water quality," *Water Supply*, vol. 11, no. 3–4, pp. 1–16, 1993.

[17] Ministry of Natural Resources and Environment Malaysia, "National Water Quality Standards For Malaysia – Annex," *Natl. Water Qual. Stand. Malaysia- Annex*, 2014, [Online]. Available: http://www.wepa-db.net/policies/law/malaysia/eq_surface.htm.

[18] M. Asrah Bin Muhamad and Z. Abidin, "Water Quality Assessment of Rainwater Collected from Rooftop at UTM," *Environ. Eng. Hydrol.*, vol. 3, 2016.

[19] "Biochemical Oxygen Demand - Water Education Foundation." https://www.watereducation.org/aquapedia-background/biochemical-oxygen-demand (accessed May 24, 2022).

[20] O. Bozorg-Haddad, M. Delpasand, and H. A. Loáiciga, "Water quality, hygiene, and health," *Econ. Polit. Soc. Issues Water Resour.*, pp. 217–257, 2021, doi: 10.1016/B978-0-323-90567-1.00008-5.

[21] Z. Hu and D. Grasso, "Water Analysis – Chemical Oxygen Demand," *Encycl. Anal. Sci. Second Ed.*, pp. 325–330, Jan. 2004, doi: 10.1016/B0-12-369397-7/00663-4.

[22] "Indicators: Dissolved Oxygen | US EPA." https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen (accessed May 25, 2022).

[23] "Oxygen in Drinking Water Supply |APEC Water." https://www.freedrinkingwater.com/water-education2/710-oxygen-water.htm (accessed May 25, 2022).

[24] H. M. Liljestrand, "Average rainwater pH, concepts of atmospheric acidity, and buffering in open systems," *Atmos. Environ.*, vol. 19, no. 3, pp. 487–499, Jan. 1985, doi: 10.1016/0004-6981(85)90169-6.

[25] K. Khayan, A. Heru Husodo, I. Astuti, S. Sudarmadji, and T. Sugandawaty Djohan, "Rainwater as a Source of Drinking Water: Health Impacts and Rainwater Treatment," *J. Environ. Public Health*, vol. 2019, 2019, doi: 10.1155/2019/1760950.

[26] "Turbidity and Water | U.S. Geological Survey." https://www.usgs.gov/special-topics/water-science-school/science/turbidity-and-water (accessed May 25, 2022).

[27] Patel, M., Pant, V., Sikligar, H., Quadri, S., Bachar, N., and Maurya, N. (2023). Harnessing conventional wisdom for rain water harvesting to mitigate the risks of climate change. *Environment Conservation Journal*, *24*(1), 157–162. https://doi.org/10.36953/ECJ.11412295.

[28] Rathore V, Bhardwaj R. Exploration of Nano-material and Thin Film Technologies for Wastewater Analysis: An Overview Curr World Environ 2023;18(1). DOI: http://dx.doi.org/10.12944/CWE.18.1.2.

[29] Tan, J., and Zou, X. Y. (2023). Water-Related Technological Innovations and Water Use Efficiency: International Evidence. *Emerging Markets Finance and Trade*, *59*(15), 4138–4157. https://doi.org/10.1080/1540496X.2023.2181663.

[30] Kartika, M. F. S., Ningsih, M. P., Saputra, M. A. D., Laila Fq, S. S. A. A., Hadianta, F. F., and Ichsan, M. H. H. (2023). Rain Harvester Prototype Integration for Drinking Water Using IoT And Mobile Apps. *Journal*

of Information Technology and Computer Science, *8*(1), 41–51. https://doi.org/10.25126/jitecs.202381452.

[31] A. M. Rodrigues, K. T. M. Formiga, J. Milograna; Integrated systems for rainwater harvesting and greywater reuse: a systematic review of urban water management strategies. *Water Supply* 1 October 2023; 23 (10): 4112–4125. doi: https://doi.org/10.2166/ws.2023.240.

[32] Waseem, M.; Mutahir Ullah Ghazi, S.; Ahmed, N.; Ayaan, M.; Kebede Leta, M. Rainwater Harvesting as Sustainable Solution to Cope with Drinking Water Scarcity and Urban Flooding: A Case Study of Public Institutions in Lahore, Pakistan. CivilEng 2023, 4, 638–656. https://doi.org/10.3390/civileng4020037.

[33] Chen, Y.; Gaspari, J. Exploring an Integrated System for Urban Stormwater Management: A Systematic Literature Review of Solutions at Building and District Scales. *Sustainability* **2023**, *15*, 9984. https://doi.org/10.3390/su15139984.

[34] Carollo, M., Butera, I., and Revelli, R.: Rainwater harvesting potential: the Turin case for an analysis at the urban scale, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-848, https://doi.org/10.5194/egusphere-egu23-848, 2023.

[35] Bakar, M. N. H. A., Latif, H. M., and Samsudin, N. S. (2023). A Road Map for Intervention Research to Enhance Rainwater Harvesting By-Laws Adherence in Malaysia: A Short Communication. International Journal of Academic Research in Business and Social Scienc, 13(6), 2034–2042.

[36] Siti Fairuz Juiani et al. 2023. *IOP Conf. Ser.: Earth Environ. Sci.* **1238** 012001. DOI: 10.1088/1755-1315/1238/1/012001.

[37] Ratnasari, A., Bhaskara Adiprabowo, A., Gilang Al Afgani, A., Widiyanti, A., and Oktavia, L. (2022). Potential of rainwater harvesting in wilayah persekutuan Malaysia. *Environmental and Toxicology Management*, *2*(2), 4–7. https://doi.org/10.33086/etm.v2i2.3410.

[38] Hudzari Haji Razali, M., Qudus Puteh, A., Haji Sulaiman, A., and Hakim Mohamad Yatim, M. (2023). Smart Rainwater Harvesting System for Sustainable Agricultural Irrigation and Drainage System. IntechOpen. doi: 10.5772/intechopen.104442.

[39] Abdul Khadir, F.K.B., Yee, N.C., Takaijudin, H.B., Zawawi, N.A.W.A., Alaloul, W.S., Musarat, M.A. Evaluation of the Implementation of Sustainable Stormwater Management Practices for Landed Residential Areas: A Case Study in Malaysia. *Sustainability* **2023**, *15*, 10414. https://doi.org/10.3390/su151310414.