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Water Quality Assessment of Roof-collected Rainwater in Miri, Malaysia

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ABSTRACT: Rainwater harvesting systems are becoming more acceptable as an alternative method to harvest water sources for both potable and non-potable uses. While the method has proven to be very simplistic and cost-effective, the collected rainwater source remains untreated and can pose serious health concerns if not used properly. This study focused on the physicochemical and heavy metal parameters of roof-collected rainwater in Miri, Sarawak. Individual sites were chosen throughout Miri, Sarawak for representative samples. Atomic Absorption Spectroscopy was used for the analysis of heavy metal concentrations. Heavy metal analysis included manganese, zinc, iron, copper, and cadmium. pH, temperature, turbidity, dissolved oxygen (DO), total suspended solids (TSS), total dissolved solids (TDS), nitrate, and fluoride were among the physicochemical parameters examined. Seasonal comparison indicated the majority of the higher concentration levels occurred during the wet season. The overall mean concentration for the physicochemical parameters indicated CLASS I usage, with the exception of BOD5, which was CLASS III usage. The overall mean concentration for metals analyzed indicated a CLASS I usage threshold with the exception of copper, which had concentrations well above the 0.02mg/L threshold for all sites. Thus, copper was considered one of the major contaminants for this study. Moreover, the types of storage tanks also showcased key findings. Open top storage tanks are more vulnerable to contamination than closed storage tanks. Metal storage tanks offer higher rainwater temperatures in comparison to other types of storage tanks.

KEYWORDS: Heavy metals; rainwater; roof-collected; seasonal; physicochemical analysis

1. Introduction

Water plays a key role in sustaining both life and development on earth, and over-exploitation and human negligence over the decades have led to a significant decrease in the availability of potable and non-potable water resources across the globe [1]. Climate change and poor water management continue to be major threats to wildlife and communities [2,3]. Previous studies indicated a strong coherent relationship between the increase in the population, urbanization, and climate change [4,5]. One of the largest foreseen issues for future generations is the water scarcity problem. The collection and treatment of water sources over the years has seen exceptional advancements in technological application to improve water quality distribution to homes, business districts and industrial areas [6]. Often, the extent to which water pipeline supplies provide water to outer urban areas and rural areas is very limited, resulting in residents relying on alternative sources of water such as rainwater harvesting for both potable and non-potable use on a daily basis [7]. Moreover, with modern treatment methods and the available flexibility of existing rainwater harvesting methods, rainwater harvesting can be considered suitable for both current and future domestic use [8].

Malaysia's climatic characteristics generate billions of cubic meters of rainwater each year, which has enabled several regions to investigate and effectively integrate roof-collected rainwater harvesting systems in business and residential locations [9]. Previous study showed that the East Malaysia region has heavier rainfall ranging from 3,000-4,000 mm [10]. This enables the customer to save money and reduce their reliance on supplied purified water. While some users prefer to use collected rainwater exclusively for non-potable purposes, others who lack access to treated water rely on such methods for both potable and non-potable purposes. This is problematic, given the majority of municipal water supplied by the approved water treatment facility is treated to fulfil health and safety standards for human consumption/use. There is a noticeable dearth of literature studies on roof-collected rainwater in Malaysia, particularly in Miri, Malaysia. With a growing reliance on roof-collected rainwater systems for domestic and non-domestic use in both residential and commercial areas, it is critical that rainwater collected is quantified and qualitatively analyzed to determine the best application for the roof-collected rainwater or the level of treatment required prior to application for the designated use. Therefore, this study aimed to carry out an assessment of roof-collected rainwater in Miri, Malaysia. The data obtained was compared to the National Water Quality Standards for Malaysia to determine the domestic usage for each site. The comparison of water quality indicators between wet and dry seasons was also evaluated.

2. Materials and Methods

2.1. Design of the study site

Roof-collected rainwater samples were collected four times from each site over a two-month period, from December 2019 to January 2020. A cross-sectional survey was conducted in urban and rural Miri, Malaysia, on both domestic and community roof-collected rainwater collecting systems. Initially, 45 suitable sites were identified; six of these sites were mostly community-based roof-collected rainwater harvesting systems, while the remaining sites included roof-collected rainwater harvesting systems used by residential families. After the study was completed, a total of 12 viable sites were identified for trial, which included both communal and domestic harvesting systems. Surveying throughout Miri indicated that most of the inner-urban areas do not practice roof-collected rainwater harvesting, although moving towards the outskirts of the urban area/entering the rural areas, residents do implement the practice (Table 1).

2.2. Sampling

Samples were preferentially drawn from the water tank storage faucet and collected using two 500mL containers. Once filled, the rainwater sample containers were tightly sealed, checked for leakage, and labelled accordingly to the site of collection, so as to prevent any potential contamination occurring. Samples were collected every month for a duration of four months. Once collected, rainwater samples were taken to the laboratory for further physicochemical parameter analysis.

Table 1. Sampling site characteristic.

Site	Location Coordinates		Type of Area	Roofing material	Remarks
1	4.491848	114.007771	Market Place	Metal	Storage tank (PE)
2	4.471947	114.015178	Residence	Metal	Open Top Storage tank (PE)
3	4.477292	114.008735	Residence	Metal	Storage tank (PE)
4	4.466620	114.007827	Community Area	Metal	Storage tank (PE)
5	4.492688	114.031196	Market Place	Metal	Storage tank (PE)
6	4.4928228	114.0312349	Market Place	Metal	Storage tank (PE)
7	4.489094	114.031280	Community Area	Metal	Storage tank (PE)
8	4.481485	114.030182	Community Area	Metal	Storage tank (PE)
9	4.475987	114.029684	Residence	Metal	Storage tank (PE)
10	4.476547	114.030432	Residence	Metal	Storage tank (PE)
11	4.446620	114.007827	Residence	Metal	Storage tank (PE)
12	4.419022	114.016672	Residence	Metal	Storage tank (PE)

2.3. Physicochemical parameters in water samples

Water sample temperature, pH, Turbidity, and DO of the influent and effluent samples were measured with a pH meter (Oakton Temp-10T, Cole Palmer, Singapore), Turbidity HACH 2100Q (Colorado, USA), and DO meter (IntelliCAL^{R} LDO101 Hach, Colorado, USA), respectively. Total suspended solids (TSS) and Total Dissolved Solids (TDS) were carried out under the 2540 D and 2540 C methods from the Standard Methods 20th Edition Report [11]. All parameter values were recorded and compared to the National Water Quality Standard, Malaysia [12]. In addition, heavy metals such as lead (Pb), copper (Cu), zinc (Zn), manganese (Mn) and cadmium (Cd) were analyzed by Atomic Absorption Spectroscopy (AAS) with the Perkin Elmer PinAAcle 900 (United States). All analysis for metal elements was carried out in triplicate.

3. Results and Discussion

Total average rainfall and rainy days were recorded during the experimental study. As per research predictions, similar precipitation was observed throughout the experimental study. More precipitation was recorded during the months of November 2019 through to January 2020 while lower precipitation was recorded for February and March 2020. Means and standard deviations are given for each of the water quality parameters presented in Table 2.

3.1. Dissolved Oxygen (DO)

In-situ DO levels of roof-collected rainwater sampled from each site over the four-month period (December 2019 to March 2020) ranged between 4.07mg/L and 9.37 mg/L, with an average value of 7.50 mg/L. Taking into account the average DO levels from each site, nine sites indicated levels above 7mg/L (CLASS I) standards while site 1, 5 and 9 showcased DO levels of 5.36, 6.88 and 6.81 mg/L respectively, classifying them as CLASS IIA/B for usage. The overall mean in-situ DO record for roof-collected rainwater collected from the storage tanks varied between tanks, with site 11 being the highest (DO 8.10 ± 0.19) and site 1 the lowest (DO 5.36 ± 1.00). Comparison between mean in-situ DO values against the wet and dry season presented 6 of 12 sites (site 1, 2, 3, 4, 10 and 11) having higher DO values during the wet season in contrast to the dry season. Conversely, the remaining 6 sites (sites 5, 6, 7, 8, 9 and 12) indicate higher DO values during the dry season than during the wet season. Nine of twelve samples indicated in-situ DO levels over 7mg/L during, which classified them as CLASS I usage while the other 3 sites (Site 1, Site 5 and Site 9) reported values of 6.06mg/L, 6.58mg/L and 6.52mg/L for the wet season (CLASS IIA/IIB). During the drier period (Dry season), 11 of 12 sites indicated in-situ DO levels above 7mg/L (CLASS I) while site 1 indicated in-situ DO levels of 4.67mg/L. Site 1, site 5 and site 9 were the only sites which indicated lower DO values for the overall mean and during the wet season. A high DO concentration within a water source essentially indicates fewer micro-organisms. This also indicates less biological contamination (e.g., pathogens, viruses, and coliforms). Low DO levels are primarily caused by algae growth, which is facilitated by the presence of phosphate and nitrogen. As algae decompose, accessible dissolved oxygen decreases as it is eaten by microorganisms. Increased breakdown rates have also been observed during drier periods as a result of increased light availability [13]. Metal easily absorbs heat during daylight, essentially slightly warming the rainwater collected and being stored. The temperature parameter has a negative correlation with the level of dissolved oxygen present within a system. Higher temperatures can easily influence the available dissolved oxygen within the water source. Additionally, the top of the storage tank is not maintained properly, which essentially encourages algae growth. Continuous weathering eventually decomposes the wood, while growing organic content promotes microorganism growth, affecting in-situ DO levels.

3.2. Biochemical oxygen demand (BOD_5)

The overall mean of BOD5 recorded for roof-collected rainwater collected from the storage tanks varied between tanks, with site 2 being the highest (BOD_5 7.56 ± 6.34) and site 11 the lowest (BOD_5 0.91 ± 1.35). Increased BOD5 values throughout the dry period would imply the presence of a considerable number of microorganisms within the roof harvesting systems' storage tanks. An increase in the BOD_5 level within a water source indicates micro-organism activity which is consuming the available oxygen. Site 1, 2, 3, 4 and 5 indicated a significant increase in BOD_5 during the months of February and March (dry season). The effect on the reduced air quality was also noticed by the Air Quality Index (data not shown). Strong winds were also apparent which conveyed the haze produced towards the city area. Betts and Jones Jr. showed that the effect of wildfire on water sources significantly increased nitrate levels [14]. Conversely, sites 6, 7, 8, 9, 10, 10, 11 and 12 reported much lower levels. Moreover, site residents do practice agricultural activities, which could explain why site 2 reported the highest BOD_5 and significant algae growth compared to other sites.

Table 2. Physicochemical parameters of roof-collected rainwater

Parameter		DO (mg/L)	BOD5 (mg/L)	Turbidity (NTU)	pH	Temperature (°C)	Nitrate (mg/L)	Fluoride (mg/L)	TDS (mg/L)	TSS (mg/L)
Site 1	Wet	6.06 ± 0.61	4.50 ± -	0.93 ± 0.29	6.69 ± 0.08	28.2 ± 0.4	0.24 ± 0.42	n.d	83.63 ± 3.25	8.80 ± 5.75
	Dry	4.67 ± 0.84	3.60 ± 2.12	1.13 ± 0.43	6.39 ± 0.50	27.7 ± 1.3	1.59 ± 0.63	0.02 ± 0.011	50.33 ± -	1.53 ± -
	All	5.36 ± 1.00	3.90 ± 1.59	1.03 ± 0.32	6.54 ± 0.34	27.9 ± 0.9	0.91 ± 0.87	0.01 ± 0.013	0.00 ± 3.73	0.00 ± 7.39
Site 2	Wet	8.01 ± 1.93	4.30 ± -	1.06 ± 0.49	7.34 ± 1.57	28.4 ± 0.1	0.10 ± 0.12	n.d	31.83 ± 4.95	7.50 ± 8.82
	Dry	7.62 ± 0.20	9.18 ± 8.04	12.79 ± 5.95	7.45 ± 0.05	26.4 ± 2.3	0.12 ± 0.17	0.01 ± 0.008	48.33 ± -	32.27 ± -
	All	7.81 ± 1.14	7.56 ± 6.34	3.73 ± 4.62	7.39 ± 0.91	27.4 ± 1.7	0.11 ± 0.12	0.00 ± 0.006	0.00 ± 1.70	0.00 ± 6.91
Site 3	Wet	7.76 ± 0.72	2.07 ± -	0.71 ± 0.24	7.25 ± 0.45	28.2 ± 0.1	n.d	n.d	40.17 ± 17.68	6.37 ± 2.31
	Dry	7.09 ± 0.38	7.70 ± 3.06	2.69 ± 1.99	6.58 ± 0.33	26.6 ± 2.2	0.10 ± 0.14	0.01 ± 0.00	30.67 ± -	2.47 ± -
	All	7.43 ± 0.61	5.82 ± 3.91	1.70 ± 1.62	6.91 ± 0.50	27.4 ± 1.6	0.05 ± 0.10	0.01 ± 0.01	0.00 ± 0.84	0.00 ± 7.07
Site 4	Wet	7.57 ± 0.72	2.27 ± -	0.43 ± 0.08	6.97 ± 0.13	28.4 ± 0.2	0.11 ± 0.15	n.d ± -	111.33 ± 12.26	4.60 ± 3.87
	Dry	7.49 ± 0.15	7.47 ± 9.99	1.25 ± 0.22	7.18 ± 1.65	26.1 ± 1.5	0.09 ± 0.13	0.01 ± 0.00	88.67 ± -	2.47 ± -
	All	7.53 ± 0.43	5.73 ± 7.68	0.84 ± 0.49	7.07 ± 0.96	27.2 ± 1.6	0.10 ± 0.12	0.00 ± 0.01	0.00 ± 0.77	0.00 ± 6.29
Site 5	Wet	6.58 ± 1.09	2.00 ± -	0.59 ± 0.06	6.23 ± 0.45	28.5 ± 0.1	0.01 ± 0.01	n.d	60.33 ± 18.38	3.50 ± 3.44
	Dry	7.18 ± 0.59	5.92 ± 3.37	0.96 ± 0.22	6.36 ± 0.00	28.1 ± 1.8	0.14 ± 0.20	0.01 ± 0.01	28.67 ± -	5.87 ± -
	All	6.88 ± 0.80	4.61 ± 3.29	0.77 ± 0.25	6.29 ± 0.27	28.3 ± 1.1	0.08 ± 0.14	0.01 ± 0.01	0.00 ± 1.21	0.00 ± 6.47
Site 6	Wet	7.78 ± 0.32	1.67 ± -	1.00 ± 0.41	6.33 ± 0.35	28.3 ± 0.1	n. d	n.d	180.67 ± 145.66	3.73 ± 3.58
	Dry	7.91 ± 0.00	1.32 ± 1.72	1.42 ± 0.61	6.62 ± 0.10	28.6 ± 1.5	0.07 ± 0.10	0.010 ± 0.001	1.67 ± -	0.53 ± -
	All	7.84 ± 0.20	1.43 ± 1.23	1.21 ± 0.49	6.47 ± 0.27	28.4 ± 0.9	0.04 ± 0.07	0.005 ± 0.006	0.00 ± 0.99	0.00 ± 7.10
Site 7	Wet	7.92 ± 0.28	2.77 ± -	0.46 ± 0.23	6.70 ± 0.05	28.2 ± 0.0	n. d	n.d	29.50 ± 16.26	6.00 ± 2.45
	Dry	8.24 ± 0.30	0.70 ± 0.85	1.52 ± 0.57	7.51 ± 0.74	28.0 ± 2.4	0.06 ± 0.08	0.009 ± 0.002	31.00 ± -	4.13 ± -
	All	8.08 ± 0.30	1.39 ± 1.34	0.99 ± 0.71	7.10 ± 0.64	28.1 ± 1.4	0.03 ± 0.06	0.005 ± 0.005	0.00 ± 1.19	0.00 ± 6.66
Site 8	Wet	7.58 ± 0.66	2.70 ± -	0.80 ± 0.63	6.17 ± 0.08	27.8 ± 0.4	n. d ± -	n. d ± -	172.83 ± 69.53	5.67 ± 0.94
	Dry	8.35 ± 0.30	0.37 ± 0.33	1.58 ± 1.68	7.15 ± 0.73	26.9 ± 2.1	0.06 ± 0.08	0.009 ± 0.002	43.00 ± -	4.07 ± -
	All	7.97 ± 0.61	1.14 ± 1.37	1.19 ± 1.13	6.66 ± 0.70	27.4 ± 1.4	0.03 ± 0.06	0.004 ± 0.005	0.00 ± 0.58	0.00 ± 6.50
Site 9	Wet	6.52 ± 0.71	2.13 ± -	0.58 ± 0.21	6.20 ± 0.32	28.2 ± 0.7	0.07 ± 0.10	n. d ± -	27.17 ± 0.71	3.50 ± 3.16
	Dry	7.10 ± 1.00	0.37 ± 0.47	0.59 ± 0.13	6.80 ± 0.74	29.4 ± 4.4	0.14 ± 0.00	0.009 ± 0.001	79.67 ± -	1.40 ± -
	All	6.81 ± 0.79	0.96 ± 1.07	0.58 ± 0.14	6.50 ± 0.58	28.8 ± 2.7	0.11 ± 0.14	0.004 ± 0.005	0.00 ± 1.61	0.00 ± 6.29
Site 10	Wet	8.25 ± 0.21	3.33 ± -	0.66 ± 0.29	6.04 ± 0.07	27.7 ± 0.8	n.d	n.d	15.67 ± 20.74	4.57 ± 0.71
	Dry	7.78 ± -	1.37 ± -	3.53 ± -	6.79 ± -	27.4 ± -	n.d	0.011 ± -	-	-
	All	8.09 ± 0.31	2.35 ± 1.39	1.61 ± 1.67	6.29 ± 0.44	27.6 ± 0.6	0.00 ± 0.00	0.004 ± 0.006	0.00 ± 0.67	0.00 ± 6.71
Site 11	Wet	8.15 ± 0.32	2.47 ± -	0.55 ± 0.18	6.27 ± 0.15	27.7 ± 0.5	0.01 ± 0.01	n.d ± -	42.50 ± 3.54	4.20 ± 0.66
	Dry	8.05 ± 0.06	0.13 ± 0.00	0.79 ± 0.18	7.15 ± 0.47	28.6 ± 1.6	0.06 ± 0.09	0.008 ± 0.012	11.33 ± -	1.80 ± -
	All	8.10 ± 0.19	0.91 ± 1.35	0.67 ± 0.20	6.71 ± 0.58	28.1 ± 1.1	0.03 ± 0.06	0.004 ± 0.004	0.00 ± 2.00	0.00 ± 6.60
Site 12	Wet	7.90 ± 0.47	2.77 ± -	2.64 ± 2.88	6.43 ± 0.21	27.2 ± 0.9	0.01 ± 0.01	n.d ± -	94.83 ± 3.06	5.83 ± 1.93
	Dry	8.28 ± 0.33	0.28 ± 0.16	1.37 ± 0.64	6.76 ± 0.01	28.0 ± 1.7	0.09 ± 0.01	0.007 ± 0.012	28.33 ± -	4.67 ± -
	All	8.09 ± 0.40	1.11 ± 1.44	2.00 ± 1.85	6.60 ± 0.23	27.6 ± 1.2	0.05 ± 0.05	0.004 ± 0.004	0.00 ± 0.00	0.00 ± 0.00

3.3. Turbidity

According to Table 2, the turbidity of roof-collected rainwater sampled from each location over a four-month period (December 2019 to March 2020) ranged between 0.29 NTU and 10.60 NTU, with an average of 1.36 NTU. Taking the total average turbidity levels from each location into account, all sites reported turbidity levels less than 5 NTU (CLASS I). Site 11 showed the highest turbidity (3.73 4.62 NTU) and site 2 was the lowest (0.58 0.14). A study by Huston et al. reported a mean turbidity level of 1.10 (with a maximum value of 9.80) from a larger data set of 352 samples collected from rainwater tanks in Brisbane, Australia [15]. Another study reported that a mean value of 0.78 from roof-collected rainwater harvesting systems in New Zealand [9]. As previously stated, site 2 was the only site to experience an algae bloom. Site 2 was also an open top storage tank; open storage tanks are easily exposed to pollutants and contaminants compared to closed tanks. Turbidity is defined as the amount of light which can scatter within the water sample. Considering the thick precipitate produced from the algae bloom, it is not an unexpected result for site 2. Effluents produced from decomposing organic matter commonly contain suspended matter in large quantities. A higher count of suspended solids within a medium effectively reduces the amount of light that is available to pass through.

3.4. pH

When considering the seasonal comparison, pH levels were higher during the wet season for sites 1 and site 3, while sites 2, 4, 5, 6, 7, 8, 9, 10, 11, 12 showcased higher pH values during the drier periods (dry season). A higher pH indicates better quality when the overall mean pH value of 6.71 is considered. Thus, dry seasons essentially produced better rainwater quality. The pH value of rainwater is easily influenced by the climate, the environment, and the type of harvesting system being used. Unless specific studies were carried out on one particular site to isolate each factor, identifying which specific factor contributed most towards influencing pH levels would be not accurate. The pH collected from the water storage tanks tended to be slightly acidic, with site 11 being the highest (pH 7.39 ± 0.91) and site 2 the lowest (pH 6.29 ± 0.44). Previous research indicated that a pH value of 6.10 (range from 4.2–10.2) was obtained from a bigger data set of 352 samples taken from rainwater tanks in Brisbane, Australia. In metropolitan locations, roof-harvested rainwater revealed mean pH values of 6.5 for galvanized steel roofing material, 6.4 for galvanized aluminum roofing material, and 6.5 for galvanized iron roofing material [15,16].

3.5. Temperature

Temperature levels of roof-collected rainwater ranged between 24.8 ºC and 32.5 ºC, with an average value of 27.8 ºC. Eight sites indicated lower temperature values during the dry season, while three sites (6, 9 and 11) indicated higher temperatures during the dry season. In comparison to plastic polymers, metal is a good conductor of heat and is easily influenced by heat sources. Using this system may cause unintentional heating of the domestic water storage, especially during the dry season. Global warming is becoming an increasingly serious issue across the globe, as evidenced by rising temperatures and increased droughts. While metal storage tanks have proven to be strong and reliable in the past, PE tanks provide better temperature control for water storage, resulting in lower evaporation risks during the storage period. The wet season would have cooler temperatures than the dry season. Although heavier precipitation typically provides more cloud cover and aids the storage tank in staying cool, such expected results were not obtained during this study except for sites 6, 9, 11, and 12.

3.6 Nitrate

Nitrate levels of the roof-collected rainwater ranged between 0.00 mg/L and 2.03mg/L, with an average value of 0.13 mg/L. While all sites were well below the 1.5mg/L (CLASS I) threshold, one site (site 1) showed levels higher than other sites. Since site 1 did have accumulated organic matter present on the roof catchment, it is possible that organic matter that fell from the trees provided the collected rainwater nitrate ions. This result is consistent with a previous study that found that the average nitrate concentration in roof-harvested rainwater in urban areas was approximately 2.8mg/L for galvanized steel roofing material, 1.1mg/L for galvanized aluminum roofing material, and 0.4mg/L for other types of galvanized roofing material. The highest nitrate levels were detected in January and February, when wildfires occurred in Miri, Sarawak. Wildfires have been identified as a source of nitrate in previous studies and may have contributed to the nitrate concentrations at each of these sites. 14] Formalized paraphrase

3.7. Fluoride

All values recorded were well below the 1.5mg/L (CLASS I) threshold set by the Department of Environment. Fluoride levels were not detected in all sites during the wet season (December 2019 and January 2020). The fluoride concentration collected from the storage tanks ranged from 0.006-0.019mg/L. Considering the geographical location of the selected sites for the experimental study, sources of airborne fluoride might originate from releasing hydrogen fluoride gases from coalfired barbeques, bushfires, cigarette smoke, insecticides, pesticides, and wind-blown dust from weathering of rocks [16].

3.8. TSS and TSD

TSS and TDS levels of roof-collected rainwater ranged from 0.53-32.27mg/L, with an average value of 5.40mg/L (CLASS I) for TSS and 1.00-283.67 mg/L, with an average value of 62.17mg/L (CLASS I) for TDS. Site 2 TSS levels during the dry season were significantly higher than all the other sites, due to algae blooms within the open-top storage tank. TDS may comprise of leaves, dust, carbonate deposits and animal dung which have been deposited onto the catchment area of the roof-collected rainwater harvesting system. Moreover, it is comprised of pollutants such as NOx and sulfur which have dissolved into water droplets during precipitation.

3.9. Manganese (Mn)

Table 3 shows the heavy metal (manganese, iron, zinc, copper, and cadmium) concentrations in roof-collected rainwater during the wet and dry seasons in the sampling location. Mn concentrations in roof-collected rainwater ranged from 0.002-0.172mg/L, with an average value of 0.052mg/L. The concentration of Mn in all sites was below 0.1 mg/L (CLASS I). This result is similar to a previous study that explored the concentration of Mn in South Korea (range of 0.07-0.170 mg/L) [18], but higher than another study in Ontario, Canada (range of 0.005 mg/L) [19].

Table 3. The heavy metal concentrations in roof-collected rainwater during wet and dry season.

Location		Mn (mg/L)	Fe (mg/L)	Zn (mg/L)	Cu (mg/L)	Cd (mg/L)
Site 1	Wet	0.059 ± 0.004	0.950 ± 0.220	0.074 ± 0.018	0.043 ± 0.006	0.007 ± 0.002
	Dry	0.013 ± -	0.637 ± -	0.075 ± 0.006	0.022 ± -	0.003 ± 0.006
	All	0.043 ± 0.026	0.845 ± 0.238	0.074 ± 0.011	0.036 ± 0.013	0.005 ± 0.003
Site 2	Wet	0.052 ± 0.015	0.740 ± 0.011	0.525 ± 0.103	0.039 ± 0.004	0.006 ± 0.002
	Dry	0.023 ± -	0.722 ± -	0.579 ± 0.082	0.030 ± -	0.002 ± 0.006
	All	0.042 ± 0.020	0.734 ± 0.013	0.552 ± 0.082	0.036 ± 0.006	0.004 ± 0.003
Site 3	Wet	0.055 ± 0.011	1.070 ± 0.175	1.089 ± 0.220	0.053 ± 0.021	0.006 ± 0.001
	Dry	0.026 ± -	0.623 ± -	1.348 ± 0.091	0.067 ± -	0.001 ± 0.006
	All	0.045 ± 0.018	0.921 ± 0.286	1.218 ± 0.203	0.057 ± 0.017	0.003 ± 0.003
Site 4	Wet	0.055 ± 0.008	0.954 ± 0.127	0.045 ± 0.011	0.046 ± 0.002	0.004 ± 0.003
	Dry	0.030 ± -	0.688 ± -	0.056 ± 0.018	0.019 ± -	0.002 ± 0.004
	All	0.048 ± 0.016	0.865 ± 0.178	0.050 ± 0.014	0.037 ± 0.015	0.003 ± 0.003
Site 5	Wet	0.064 ± 0.010	0.876 ± 0.095	0.077 ± 0.018	0.104 ± 0.091	0.005 ± 0.002
	Dry	0.069 ± -	0.610 ± -	0.063 ± 0.031	0.017 ± -	0.002 ± 0.005
	All	v10 ± 0.008	0.787 ± 0.168	0.070 ± 0.022	0.075 ± 0.081	0.003 ± 0.002
Site 6	Wet	0.120 ± 0.074	1.024 ± 0.112	0.084 ± 0.004	0.053 ± 0.016	0.007 ± 0.003
	Dry	0.013 ± -	0.663 ± -	0.069 ± 0.000	0.025 ± -	0.002 ± 0.008
	All	0.084 ± 0.081	0.903 ± 0.223	0.077 ± 0.009	0.043 ± 0.020	0.004 ± 0.004
Site 7	Wet	0.061 ± 0.009	0.937 ± 0.178	0.048 ± 0.005	0.040 ± 0.014	0.004 ± 0.004
	Dry	0.002 ± -	0.553 ± -	0.050 ± 0.012	0.013 ± -	0.000 ± 0.007
	All	0.041 ± 0.034	0.809 ± 0.255	0.049 ± 0.008	0.031 ± 0.019	0.002 ± 0.003
Site 8	Wet	0.058 ± 0.013	1.148 ± 0.383	0.040 ± 0.013	0.047 ± 0.002	0.002 ± 0.001
	Dry	0.006 ± -	0.633 ± -	0.057 ± 0.004	0.014 ± -	0.000 ± 0.003
	All	0.041 ± 0.031	0.976 ± 0.402	0.048 ± 0.013	0.036 ± 0.019	0.001 ± 0.001
Site 9	Wet	0.072 ± 0.018	0.914 ± 0.033	0.611 ± 0.027	0.070 ± 0.016	0.007 ± 0.002
	Dry	0.020 ± -	0.588 ± -	0.557 ± 0.311	0.015 ± -	0.000 ± 0.009
	All	0.055 ± 0.033	0.805 ± 0.189	0.584 ± 0.183	0.051 ± 0.034	0.003 ± 0.004
Site 10	Wet	0.064 ± 0.012	0.876 ± 0.122	0.404 ± 0.018	0.045 ± 0.003	0.003 ± 0.003
	Dry	nd	nd	0.463 ± -	nd	nd
	All	0.064 ± 0.012	0.876 ± 0.122	0.424 ± 0.036	0.045 ± 0.003	0.002 ± 0.003
Site 11	Wet	0.061 ± 0.001	0.466 ± 0.573	0.555 ± 0.536	0.044 ± 0.033	0.004 ± 0.005
	Dry	0.004 ± -	0.679 ± -	1.008 ± 0.136	0.014 ± -	0.001 ± 0.006
	All	0.042 ± 0.033	0.537 ± 0.424	0.782 ± 0.413	0.034 ± 0.029	0.002 ± 0.003
Site 12	Wet	0.069 ± 0.001	0.895 ± 0.098	1.470 ± 0.035	0.049 ± 0.010	0.004 ± 0.001
	Dry	0.014 ± -	0.624 ± -	1.362 ± 0.265	0.013 ± -	0.000 ± 0.006
	All	0.051 ± 0.032	0.804 ± 0.171	1.416 ± 0.167	0.037 ± 0.022	0.002 ± 0.002

Note: nd = not detected

3.10. Iron

Over a four-month period, iron (Fe) concentrations at each site ranged between 0.060mg/L and 1.418mg/L, with an average of 0.822mg/L. The overall mean Fe concentrations at each site were less than 1mg/L. (THE FIRST CLASS).The TSS value for roof-collected rainwater varied between tanks, with site 8 reporting the highest value (Fe 0.976 0.402) and site 11 reporting the lowest value (Fe 0.537 0.424). In comparison to previous research, Huston et al. reported an Fe concentration of 0.068mg/L (with a maximum of 4.4mg/L) from 88 samples collected from rainwater tanks in Brisbane, Australia [18]. Lee et al. reported an Fe concentration of 0.302mg/L for galvanized steel roofing material, while Mendez et al. reported a Fe concentration of 0.590mg/L for galvanized aluminum roofing material [18,20].

3.11. Zinc

The average Fe concentrations at each site were less than 5mg/L, indicating CLASS I. Site 12 was reported as the highest concentration (1.416 mg/L), while site 8 was reported as the lowest concentration (0.048 g/L). In comparison to previous studies, Huston et al. reported a Zn concentration of 0.770 mg/L (with a maximum of 26mg/L) from 361 samples collected from rainwater tanks in Brisbane, Australia [15]. A previous study on roof-harvested rainwater in urban areas discovered that a Zn concentration of 0.428 mg/L for galvanized steel roofing material and 0.375 mg/L for galvanized aluminum roofing material. The Zn concentration in this study was slightly lower than that in subsequent studies reviewed by Sánchez et al. [16].

3.12. Copper

The average copper concentration at all sites was less than 0.2 mg/L, classifying it as CLASS IV. The overall copper concentration in roof-collected rainwater varied; site 5 reported the highest concentration (0.075 mg/L) and site 7 reported the lowest concentration (0.031 mg/L). Previous studies reported that copper was detected in roof-collected rainwater in Brisbane (0.021 mg/L) [15]. Metal roofing material and pipe valves used in the storage tank were suggested as the main reasons for the occurrence of copper in roof-collected rainwater. Most likely, the pipe valve and the roof made from copper have eroded, resulting in higher copper concentrations.

3.13. Cadmium

The average Cd concentration in all sampling locations was less than 0.01mg/L, indicating that they were classed as CLASS I. Site 1 had the greatest copper concentration (Cu 0.005 0.003), while site 8 had the lowest (Cd 0.001 0.001). In comparison to other studies, Cd was also detected in roof-harvested rainwater in Ontario, Canada (0-0.005 mg/L), South Korea (0-0.0040 mg/L), and South Africa (0-0.0006 mg/L). The result in this study was higher than the majority of the previously reported values but comparable to the study conducted in Ontario, Canada by Despins et al. [19].

4. Conclusions

The quality of rainwater collected from individual rooftop rainwater harvesting systems in Miri, Sarawak, was determined using physicochemical and heavy metal parameters. Contamination (nutrients and metals) of stored rainwater tanks could be caused by the components of a certain rainwater system being in poor condition (catchment area, gutter, piping and storage tanks). For seasonal comparisons, the majority of results from the 12 sites indicated that concentrations of BOD5, TSS, TDS, and all five heavy metals examined were higher during the rainy season. It is obvious that increased precipitation results in more contamination entering the storage tank. As a result, an older rainwater collecting system has more rusted components, which transmit higher metal concentrations to the storage tank, as well as elevated TSS and TDS levels. On the other hand, there are sites that have a higher concentration of some factors during the wet season. These findings imply that external factors may potentially contribute to the overall water quality of a rainwater system.

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Competing Interest

There is no competing interest to declare.

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