Harvested Rainwater Quality Assessment on the Effects of Roof Materials to the First Flush Runoff

Janice Lynn Ayog*, Salinah Dullah & Rosdianah Ramli
Civil Engineering Program, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.
*Corresponding author. E-Mail: jay@ums.edu.my; Tel: +6088-320000; Fax: +6088-320348.

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Abstract
This study focuses on the effects on roofing materials on the first flush runoff quality. An experimental rainwater harvesting system was designed and built on the compound of the Civil Engineering Hydraulic Laboratory, Universiti Malaysia Sabah, to assess the effects of two different types of roofs - locally-sourced nipah-thatched roof and galvanized iron roof – on the quality of the harvested rainwater in the university. The first flush runoff from the rainwater collected on the 8th June 2015 was analysed for four water quality parameters, namely pH, total suspended solids (TSS), turbidity and dissolved oxygen (DO). The results obtained from this study were then checked to the water quality threshold limit of the Interim National Water Quality Standards for Malaysia (INWQS) and compared to selected previous studies. It is found that the first flush runoff quality for the nipah-thatched and the galvanized iron roofs were relatively good, except for turbidity (nipah-thatched roof only) and DO. The pH concentration levels from this study is in neutral range (5-7) as most previous researches, but the TSS concentration levels were relatively lower. The turbidity and DO levels of the galvanized iron roof were quite similar with other roofs, however the nipah-thatched roof had higher concentration levels as compared to the previous studies. As the water quality results could be influenced by the roof age, further investigation will be done on this factor to the harvested rainwater quality.

Introduction

Water supply is very important for the survival of a community. Despite its role as a crucial resource, the World Water Council projected that the demand for water within the next fifty years will increase due to a prediction of 40-50% population growth coupled with industrialization and urbanization (Mahmoud *et al.*, 2014). An estimated two billion people will lack access to safe drinking water by the middle of this century (Parmar, 2003). The demand for clean water has doubled every 21 years (Li *et al.*, 2010) despite the depletion of water supply due to environmental issues such as water pollution. One of the approaches to tackle the problem of limited access to water is the identification and utilization of additional sources of water to supplement existing or dominant sources, where one of the sources identified is harvested rainwater (Opare, 2012). This is especially true for tropical countries where perennial rainfalls occur throughout the year. Rainwater harvesting is the capture of rainwater from a roof or the ground for potable or non-potable use. Although rainwater can be used for both potable and non-potable uses (Li *et al.*, 2010; Opare, 2012; Ellias *et al.*, 2011), Che-Ani *et al.* (2009) claimed that it is best used for non-consumptive purposes.

Rainwater harvesting (RWH) is a traditional yet sustainable method to collect and store rainwater (Law & Bustami, 2009; Rahman *et al.*, 2014). It is simple and could be one of the most adaptable methods in mitigating the water scarcity (Rahman *et al.*, 2014). However, there are contaminants found in the harvested rainwater that degrades its quality, among others are heavy metals and pathogenic bacteria. The importance of harvested rainwater quality is significant because it is increasingly being used for domestic purposes. The decline of harvested rainwater quality could occur during any of these three stages: wet depositions (the deposition of atmospheric pollutants by the rainfall), dry deposition & organic matter (the wash-off of pollutants deposited on the surface of the catchment) and first flush deviation & storage contamination (Sánchez *et al.*, 2015; Lathan & Schiller, 1984). As this study emphasizes more on the first flush runoffs, the second and the third stages of the harvested rainwater contamination will be of greater focus.

Roofing materials and first flush runoff quality: previous studies

Table 1. Mean values of harvested rainwater quality based on roof types: first-flush tank only

Roof types	pH	TSS (mg/l)	Turbidity (NTU)	DO (mg/l)	Reference
Wooden Shingle [WS]	6.8	214	-	-	Sánchez *et al.* (2015); Lee *et al.* (2012)
Concrete tile [CoT]	7.1	309	-	-	
Clay tile [ClT]	7.1	219	-	-	
Galvanized steel [GS]	6.5	286	-	-	
Asphalt fibreglass shingle [AFS]	6.2	45	33	-	Sánchez *et al.* (2015); Mendez *et al.* (2010); Mendez *et al.* (2011)
Galvanized aluminium [GA]	6.4	105	96	-	
Concrete tile [CoT]	6.9	70	51	-	
Cool roof [CoR]	6.4	95	67	-	
Green roof [GR]	6.5	12	4	-	
Galvanized iron [GI]	6.5	91	-	-	Sánchez *et al.* (2015); Yaziz *et al.* (1989)
Concrete tile [CoT]	6.5	153	-	-	
Treated wood [TW]	6.1	-	-	-	Sánchez *et al.* (2015); Nicholson *et al.* (2009)
Waterproof wood [WW]	5.4	-	-	-	
Cedar shakes [CS]	4.0	-	-	-	
Asphalt shingles [AS]	6.6	-	-	-	
Galvanized roof [GaR]	6.1	-	-	-	
Green roof [GR]	7.5	-	-	-	
Asbestos cement [AC]	6.6	-	0.6	-	Sánchez *et al.* (2015); Olaoye & Olaniyan, (2012)
Aluminium roof material [AR]	6.9	-	0.1	-	
Concrete flat roof [CFT]	6.1	-	0.9	-	
Corrugated plastic roof [CPR]	6.4	-	0.2	-	
Clay tiles [ClT]	6.5	20.9	-	0.87	Gikas & Tsihrintzis (2012).
Concrete flat roof [CFR]	6.8	10.0	-	1.29	

The discoveries made by Yaziz *et al.* (1989) while evaluating the effects of using galvanized-iron and concrete tile roofs on the rainwater quality found that rainfall intensity affected the quality of rainwater runoff (dry deposition rainwater contamination stage). Gikas & Tsihrintzis (2012) found that the installation of the first flush diverters improved physicochemical quality of the collected rainwater in the storage tanks for both roofs, but not for the sanitary quality. Lee *et al.* (2012) determined that the galvanized steel is most suitable to be used after the first flush. In Austin, Texas, Mendez *et al.* (2010) and Mendez *et al.* (2011) analysed the rainwater samples from five roof types and found that rainwater harvested from any roof type would require treatment in order to meet the primary and secondary drinking standards, or the non-potable water reuse guidelines.

Table 1 lists the mean concentration values of pH, total suspended solids (TSS), turbidity and dissolved oxygen (DO) from selected studies done previously, aiming only on the first flush runoff quality. These results are used to be compared to the pollutant concentration level obtained from this study.

Materials and methods

A small-scale rainwater harvesting system, equipped with first flush diverters, was built on the compound of the Civil Engineering Hydraulic Lab, Universiti Malaysia Sabah (6˚2’5.06’’E, 116˚7’24.49’’E), to evaluate the effects of two types of roofs (locally-sourced nipah-thatched roof and corrugated galvanized iron roof) on the quality of the harvested rainwater in the university. The roofs were placed on top of the steel frames, with the roof area approximately 2 meter in length and 1 meter in width for each roof type. The system developed consists of several components – roof as the catchment area, gutters, the first flush diverters and rain tanks. The volume of the first flush diverters were 1.0 litre, designed based on the average annual rainfall in Kota Kinabalu, Sabah and the system’s roof area.

Table 2. INWQS concentration limits and classes for pH, TSS, turbidity and DO

Parameters	Class					
	I	IIA	IIB	III	IV	V
DO (mg/l)	7	5-7	5-7	3-5	<3	<1
pH	6.5-8.5	6-9	6-9	5-9	5-9	-
TSS (mg/l)	25	50	50	150	300	300
Turbidity (NTU)	5	50	50	-	-	-

Class		Uses
I		Conservation of natural environment; Water Supply I – Practically no treatment necessary; Fishery I – Very sensitive aquatic species
II	IIA	Water Supply II – Conventional treatment; Fishery II – Sensitive aquatic species
	IIB	Recreational use body contact
III		Water Supply III – Extensive treatment required; Fishery III – Common of economic value and tolerant species; livestock drinking
IV		Irrigation
V		None of the above

The rainwater sample from this system was collected on the 8th June 2015. The water sample were removed from the first flush bottles and analysed for pH, total suspended solids (TSS), turbidity and dissolved oxygen (DO) at the Civil Engineering Environmental Lab, Universiti Malaysia Sabah. The results obtained from these samples were then checked with the concentration level threshold limits of the Interim National Water Quality Standards for Malaysia (INWQS) and compared with the water quality results from the selected previous studies. Table 2 shows the INWQS concentration limits and water classes and uses for pH, TSS, turbidity and DO.

Result and discussion

Table 3 shows the results of the first flush runoff quality for the two roofs. The concentration levels of pH, TSS, turbidity and DO obtained from this analysis were compared to the Interim National Water Quality Standards for Malaysia. It can be seen that the first flush runoff water quality for these roofs were relatively good, except for turbidity (nipah-thatched roof) and DO (both roofs), which could possibly be due to the fact that the sampling activities were done immediately after the installation and cleaning of the rainwater harvesting system. As the first flush runoff quality is influenced by the age of the roof, it is expected that the water quality in the first flush diverter will deteriorate with a longer roof age.

Table 3. Mean values of harvested rainwater quality based on nipah-thatched and galvanized iron roofs in Universiti Malaysia Sabah: first-flush tank only

Roof types	**pH**	**INWQS Class**	**TSS (mg/l)**	**INWQS Class**	**Turbidity (NTU)**	**INWQS Class**	**DO (mg/l)**	**INWQS Class**
Nipah-thatched [NT]	7.05	I	44	IIA	58.4	III	2.37	IV
Galvanized iron [GI]	6.43	II	42	IIA	1.53	I	0.80	V

Fig. 1 to Fig. 4 shows the comparison of results between this study and selected previous research. The number in the bracket ([]) indicates the references of which the values were obtained from. It can be observed that the pH concentration levels from this study was comparable to the results from the most studies, which are between 5-7. The TSS concentration levels were relatively lower; the TSS levels for the galvanized iron roof in this study was lower than in Yaziz *et al.* (1989) – which could probably be explained by the difference in the age of the roofs. The turbidity and DO levels of the galvanized iron roof were quite similar with other roofs, however the nipah-thatched roof yielded higher concentration levels as compared to the previous studies.

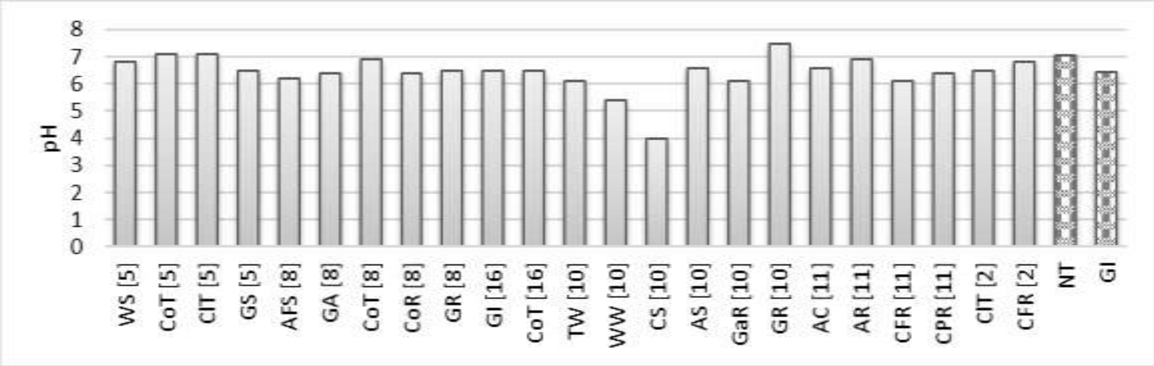

Figure 1. The pH results from the UMS RWH system and previous studies

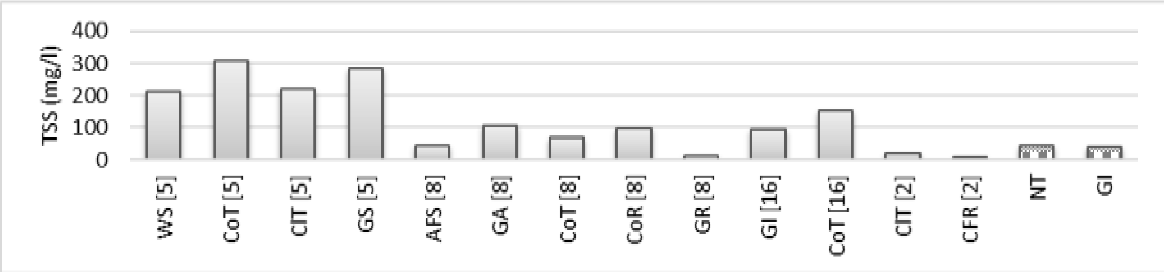

Figure 2. The TSS (mg/l) results from the UMS RWH system and previous studies

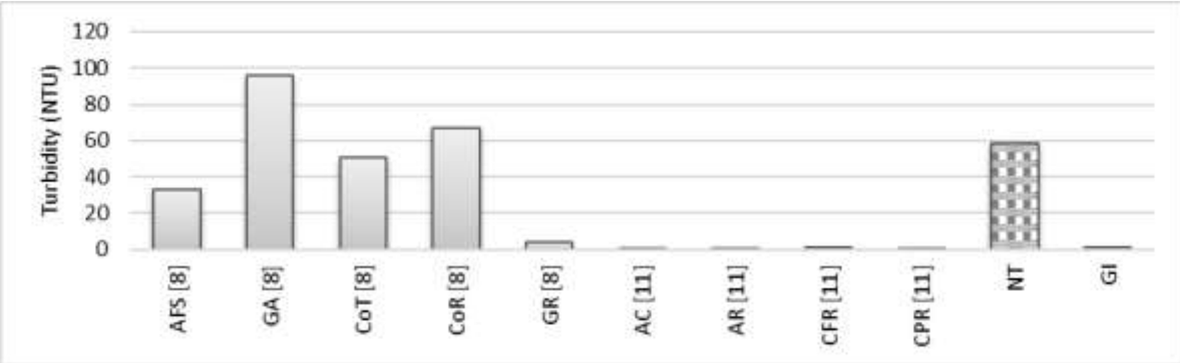

Figure 3. The turbidity results from the UMS RWH system and previous studies

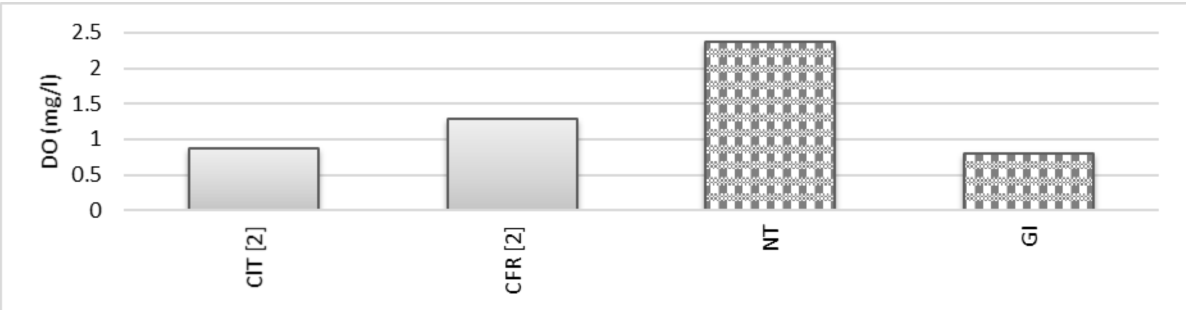

Figure 4. The DO (mg/l) results from the UMS RWH system and previous studies

Conclusion

From this study, it can be concluded that the first flush runoff quality for the nipah-thatched roof and the galvanized iron roof were relatively good, except for turbidity (nipah-thatched roof only) and DO, which could be because of the sampling activities was done just after the rainwater harvesting system being installed and cleaned. Further research will be done to investigate the effects of the age of the roofs on the harvested rainwater quality, both for first flush and storage tanks. This study will also further address the influence of roofing materials on the trace and metal concentration levels, as all previous studies indicated higher concentration level of some metals on the harvested rainwater quality.

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