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Effects of roof pitch gradient and material to harvested rainwater quality

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Abstract. Rainwater harvesting has untapped potential in domestic usage due to the lack of awareness and design guidelines to building sustainable roofs. Studies suggest that combinations of different roof pitch gradient and materials will affect the runoff quality. The level of contamination and contents found in the harvested rainwater will require different ways for water treatments prior to usage. The objective of this research is to identify design criteria of a building roof affecting the roof runoff quality in Kuala Lumpur. Quantitative analysis is done based on the rainwater collected from case studies with combinations of different roof pitch and materials to identify the contents and level of contamination in each of the collected sample. The result observed the best runoff quality from clay tile roof of 45°, metal roof of 15° and polycarbonate roof of 15°; whilst reinforced concrete (RC) flat roofs harvested the most contaminated runoffs. The study shows that all roof runoff quality is not up to potable standard though can be used for indoor non-potable use with minimal treatment.

1. Introduction

Water scarcity has become the top global crisis causing pressure on the resources that are vital for human survival. [1][2] Rainwater harvesting (RWH) has emerged as one of the best solutions to relieve urban issues such as flash flood and high demand for treated water. [3] Other than ground-surface storm water collection, rainwater is more commonly collected from above-ground rooftop catchment areas which are potentially less polluted and easily treated for domestic use. [4][5][6]

Various studies have identified the relation between roof material and runoff quality with different outcomes due to the difference in climate, context and variation of each material in different localities [7]. Ferreny et al. (2011) suggested that flat gravel roofs harvested the most contaminated rainwater. [8] The pattern observed from this research is that sloping smooth roof will result in the best quality and quantity of roof run-offs. Studies conducted by Lee et al. (2012), Olaoye et al. (2012) and Despin et al. (2009) showed similar results with best harvested runoff quality from steel and aluminium roofings; [3][7][9] while Simmons et al. (2001) discovered that lead contamination was found higher in RWH systems with lead or galvanized iron as part of the system. [10] Chang et al. (2004) suggested that the reduction of zinc used in constructing RWH system and components is essential to reduce zinc pollution. [11] Abbott et al. (2007) conducted a research on the micro-biological quality of roof –harvested rainwater in relation to the awareness of the respective residents on rainwater and roof maintenance. [12] As important as the awareness of end-users to maintain their roofs and to treat the harvested rainwater, the cost and effort of doing so can be reduced if the roof design and material are optimized in the beginning.

2. Methodology

The research was done within University Malaya campus in Kuala Lumpur to ensure consistency of the microclimate and urban activities which will affect the rainwater quality. Nine (9) roofs were selected as case studies (three clay tile roofs, two metal roofs, two polycarbonate roofs and two RC flat roofs) based on deciding factors such as the roof material and pitch gradient as well as controlling factors such as building height at one storey and availability of drip-off collection point.

Rainwater drip-off from the roof eaves of the nine selected case studies and one ambient rain sample (controlled sample) were collected during a drizzling rain event (wet season). Approximately 400 ml of rainwater for each case study was collected in a laboratory container for physical tests and IC test; while another 10 ml was acidified on site with 3 drops of diluted hydrochloric acid for ICP test. Due to the low visibility and time restriction during on-site data collection, physical tests were conducted in the laboratory as soon as data collection is completed.

Table 1. Tabulation of sample coding based on roof attributes.

Roof Type	**Clay Tile**			**Metal**		**Polycarbonate**		**RC Flat Roof**		**Ambient Rain**
Pitch	15°	30°	45°	15°	30°	15°	30°	<5°	<5°	-
Code	C1	C2	C3	M1	M2	P1	P2	RC1	RC2	A1

Table 2. Tabulation of precipitation data for sample collection.

Parameter	**Units**	**Method / Test**
Physical		
pH	upH	pH benchtop meter
Conductivity	µs/cm	Portable multiparameter meter
Total suspended solid (TSS)	ppm	
Salinity	psu	
Chemical		
Ions (F-, Cl-, NO_2-, NO_3-, SO_{4-2})	mg/L	Ion chromatography test (IC test)
Heavy Metal (Al, Zn, Fe)	mg/L	Inductively coupled plasma test (ICP test)
Hardness (Ca, Mg)	mg/L	

The results of each parameter were plotted into graphs, where performances were compared between samples and National Water Quality Standards (NWQS) for Malaysia. The discussion of each graph will lead to a spider chart marked for each sample for a clearer picture of its general attributes in terms of rainwater harvesting efficiency and performance.

3. Results and Discussion

Table 3. Tabulation of results.

Parameters	Units	C1	C2	C3	M1	M2	P1	P2	RC1	RC2	A1
Physical											
pH	upH	6.91	7.18	7.15	6.20	5.51	5.57	5.21	7.35	7.51	7.18
Conductivity	µs/cm	80.76	57.73	56.46	11.81	17.82	20.11	37.42	105.6	117.0	10.44
Total Dissolved Solid	mg/L	39.64	29.03	27.64	6.30	9.31	10.55	18.68	52.55	58.22	5.57
Salinity	psu	0.09	0.08	0.08	0.06	0.06	0.07	0.07	0.103	0.1	0.06
Main Ions											
Nitrate, NO_3^-	mg/L	5.00	4.53	2.89	1.68	3.23	2.29	5.81	1.04	0.31	0.90
Sulphate, SO_4^-	mg/L	4.55	3.07	1.98	1.89	2.17	1.70	3.31	3.86	3.44	0.81
Hardness											
Calcium, Ca	mg/L	13.71	9.19	9.62	0.31	0.42	0.41	3.56	18.71	22.49	0.31
Magnesium, Mg	mg/L	0.12	0.25	0.17	0.01	0.04	0.01	0.05	0.31	0.17	0.01
Heavy Metal											
Aluminium, Al	mg/L	0.13	0.14	0.15	0.47	0.49	0.45	0.43	0.11	0.17	0.47
Zinc, Zn	mg/L	0.08	0.04	0.02	0.04	0.18	0.08	0.24	0.02	0.03	0.04
Iron, Fe	mg/L	0.02	0.03	0.01	0.01	0.45	0.01	0.05	0.13	0.01	0.01

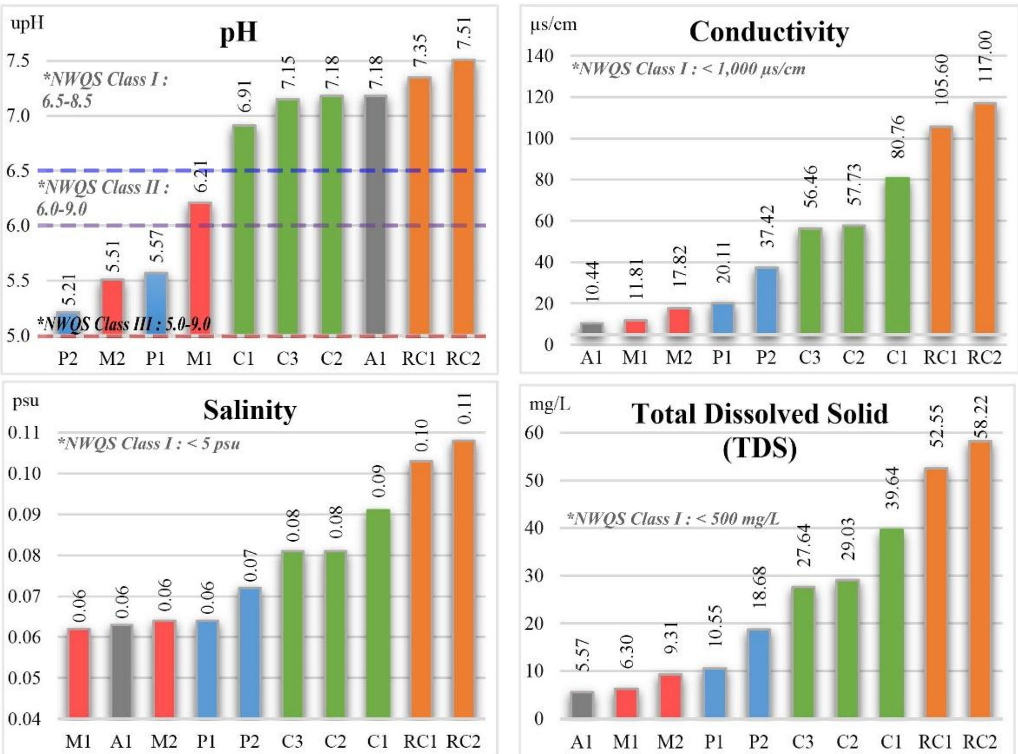

Figure 1. Graphs in ascending order of pH value, conductivity, salinity and TDS for each sample.

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3.1. pH

Clay tile roof-harvested rainwater displays a rather neutral reading, similar to that of ambient rain, indicating that clay tile does not significantly affect runoff pH value. Both polycarbonate roof and metal roof harvest rainwater that shows low pH value, which is in contradict with other similar researches. However the source of acidity is not identified. Lower pH value from metal and polycarbonate roof runoffs caused the high level of aluminium corrosion from the roofs, suggesting that both metal roofs are made up of alloy metals containing aluminium. Although polycarbonate sheets have no metal content, heavy metal contamination can still come from glazing bars and metal crossbraces.

3.2. Conductivity, Salinity and TDS

The graphs indicates the highest level of active ions in rainwater harvested from RC flat roofs, followed by clay tile roofs, polycarbonate roofs and metal roofs. Sources of active ions include dissolved salt or mild acids such as the most commonly found hydrochloric acid. Active ions in the form of calcium or magnesium are also one of the main contributor to the water hardness. In this research, the active ions found in RC flat roof runoffs are mostly from dissolved salt and hardness, given the non-acidic pH value recorded.

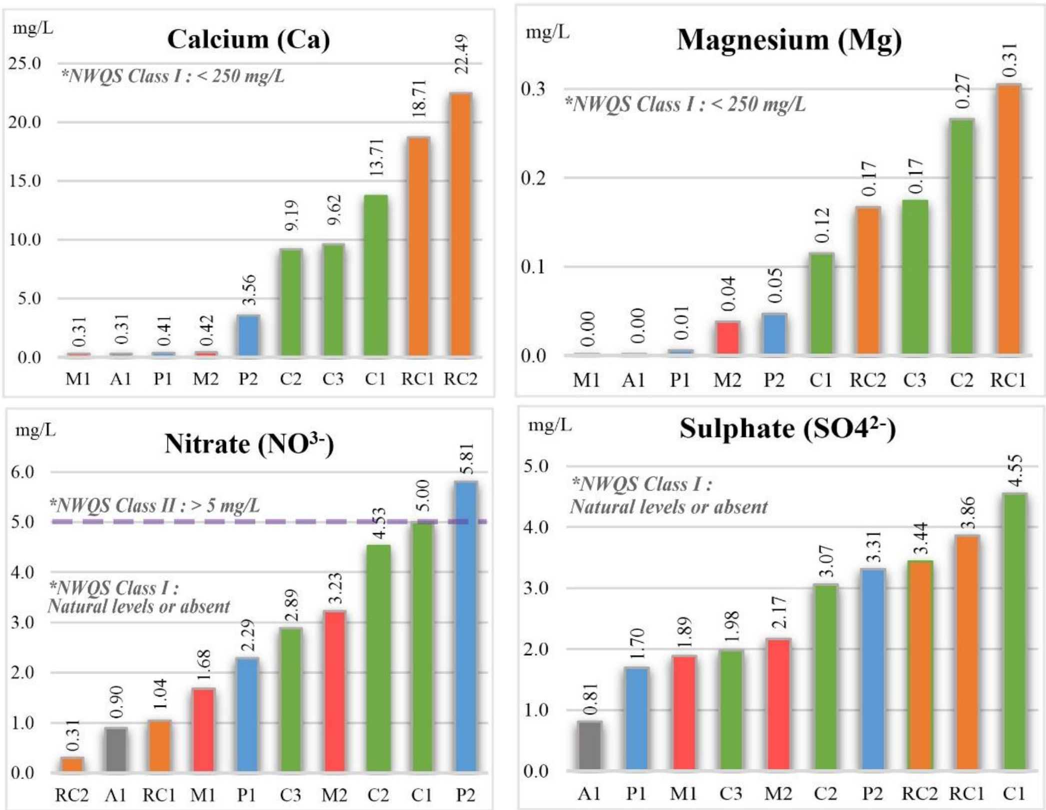

Figure 2. Graphs in ascending order of hardness and mineral content for each sample.

3.3. Hardness

The significant existence of calcium and magnesium content found on clay tile roof and RC flat roof might be due to the dissolution of calcium carbonate and magnesium carbonate compound from the concrete and lime related surfaces - from the screeding or paint.

The higher level of calcium and magnesium found in clay tile roof and RC flat roof runoffs are explanatory to the pH graph as well, due to the alkalinity of both components. Both metal roof and polycarbonate roof yielded relatively soft rainwater quality, requiring less treatment to soften the water for household cleaning purposes.

3.4. Minerals

Higher degree of porosity from clay tiles will result in the growth of lichens and mosses, thus showing a higher reading of nitrate contents. [5] Therefore, maintenance for clay tile roof is relatively important due to the surface texture which can easily contain moisture and sedimentations. Nitrate content from metal roof M2 might come from the decaying of fallen leaves or fecal deposited by birds or rodents. The roof was observed to be poorly maintained, resulting in a higher yield of nitrate contamination. C1 showed the highest reading in terms of sulphate pollution due to the low gradient and that the porosity of clay tiles in retaining sulphate related substances.

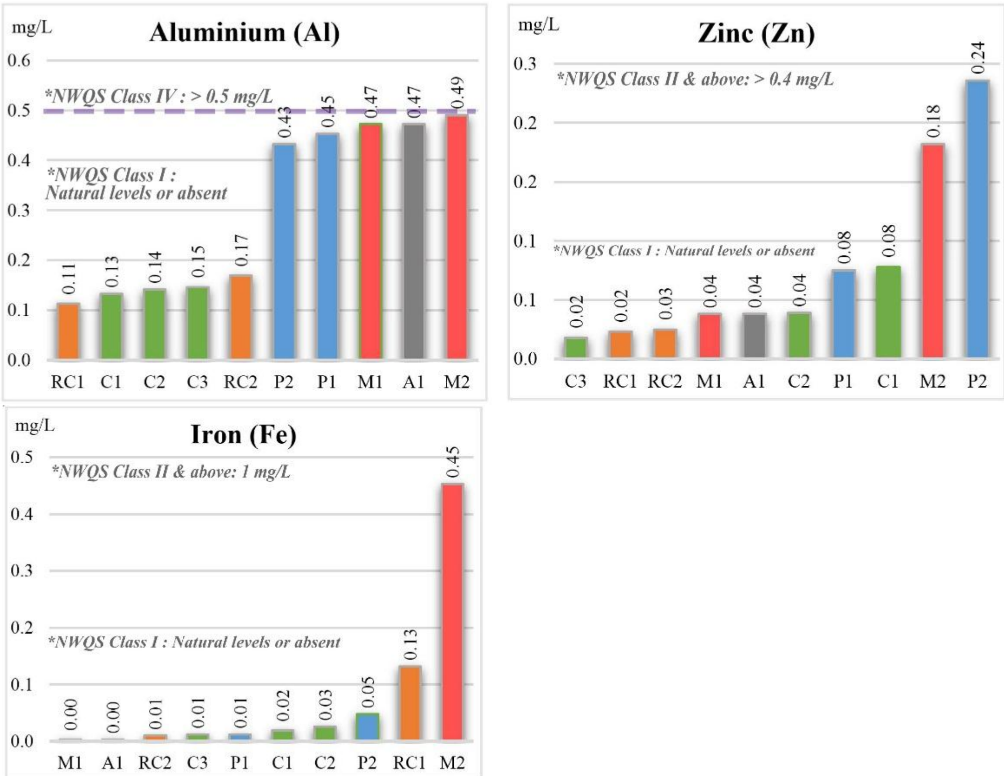

Figure 3. Graphs in ascending order of hard metal content for each sample.

3.5. Heavy metals

Given the low pH value in their runoff, P1, P2 and M2 are observed to have rusty surfaces and metal frames, contributing to the corrosion of aluminium compound on the roof surface. M1 can be identified as aluminium coated metal roof or that the component of the metal sheets contained aluminium compound which is easily corroded.

M2 and P2 showed significant reading in the zinc concentration graph. M2 and the metal frames on P2 are observed to be rusty and lack maintenance. The oxidation of alloy metal sheets might result in a mix of corroded metal remaining such as zinc and aluminum on the roof surface, which is then washed down through the runoffs. M2 showed the highest reading for iron content. Runoff from M2 contained high levels of aluminum, zinc and iron, due to the rustiness and debris deposited on the roof from fallen leaves or animal feces.

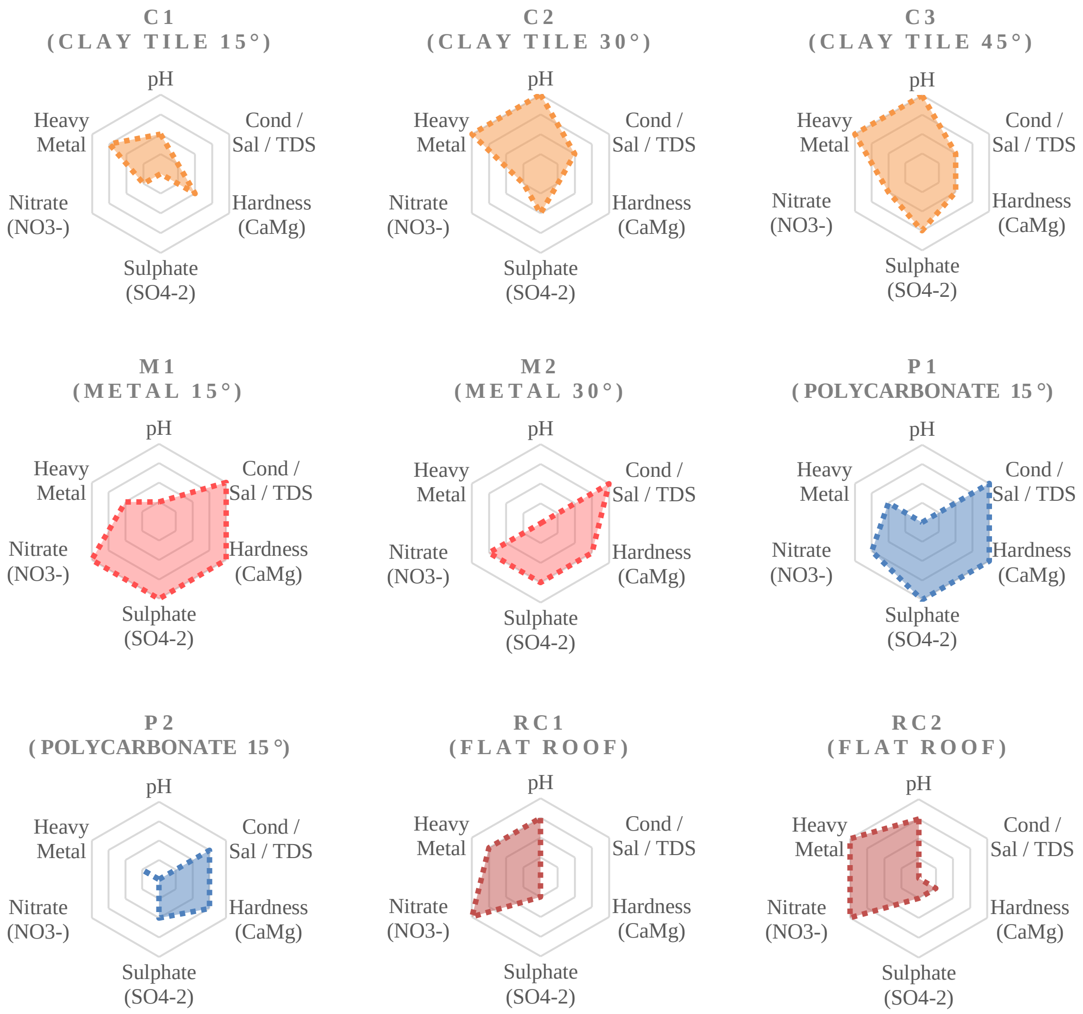

Figure 4. Spider charts showing performance of each case study roof based on the attributes tested.

4. Conclusion

The result observed the best runoff quality from clay tile roof of 45°, metal roof of 15° and polycarbonate roof of 15°; whilst RC flat roofs harvested the most contaminated runoffs. The study shows that all roof runoff quality is not up to potable standard; though can be used for indoor non-potable use with minimal treatment. Besides raising awareness on effects of roof design and material to quality of harvested rainwater, findings of this research are able to identify design criteria of a building roof affecting the roof runoff quality without first flush system. This will aid practitioners in designing sustainable roofs within the local context. This research will serve as a guideline and reference to achieve water and energy efficient roof designs based on the intended usage of roof harvested rainwater, particularly for designers, authorities, manufacturers as well as green rating tools.

This research was conducted with several limitations addressed, including matters related to case study selection and lack of resources. Firstly, the study focused solely on the runoff quality harvested from immediate catchment area – the roof surface, while other RWH mediums such as gutters, rainwater downpipe and storage tanks are not involved. The selection of case studies were done based on observation, where there might be slight variation of recorded roof pitch degree and building height. Proximity between all case studies were also considered, given the lack of human resources during the data collection, which is required to take place within the first flush of rain event. The roofing materials are of different grades and quality, installed at different point of time, with different maintenance routine. Due to the lack of funding for laboratory test, only one rain event is adopted for data collection, thus there is no result comparison done on multiple rain events.

Further research can be done in consideration of the mentioned limitations, where pilot roofs can be installed and observed over a certain period of time to obtain a more accurate data for comparison. The effects of different grades and quality of the same type of roofing material can also be studied to identify the optimal quality desired for respective material with suitable installation method. Research of microbial contaminations on different types of roof material is also important to reduce health related issues from consumption of harvested rainwater and for development of roof materials that are less prone to microbial growth. The study of runoff quality through overall RWH system from collection point to storage can also be useful to optimize the potential of rainwater for domestic use.

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