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Quality assessment of harvested rainwater from green roofs under tropical climate

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ABSTRACT

With respect to the current vulnerable climatic condition, water quality has become a matter of the highest worldwide concern. Rainwater harvesting is the most acceptable solution for overcoming this problem. Among various rainwater harvesting systems, green roof rainwater harvesting is a significant tool for improving the standard of living for rapidly growing populations in the whole world, in terms of both water demand and protecting the environment from pollution. This paper assesses the water quality parameter (dissolved oxygen (DO), pH, conductivity, and temperature) of rainwater harvesting from green roofs in humid tropic center under tropical climate conditions. It shows that the values of electric conductivity are always within Class I according to Interim National Water Quality Standards (INWQS) and Water Quality Index (WQI). Depletions of DO and pH values were observed for the green roof runoff, and the runoff quality ranged between Class I and III under INWQS and WQI. Lower value of pH indicates that harvested rainwater from green roofs is more acidic than the standard neutral value. Harvested water must be processed through general water treatment methods like filtration, disinfection, and through reverse osmosis storage tank. The indoor temperatures are always within an acceptable range.

Keywords: Rainwater harvesting; Green roofs; MSMA SME; Water quality parameter; Water treatment; INWQS and WQI

1. Introduction

Rainwater harvesting has an established historical past as a philosophy as well as a technology for water management and supply [1]. This system has been used in almost every part of the world by all societies. The Earth's most elevated source of fresh water is rain, and rainwater harvesting has a vital role to play in water resource and watershed management. Due to rapid increase in population, rapid urbanization, and

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global change, water demand is increasing day-by-day and causes water shortages. Rainwater harvesting has been identified as a useful technology for mitigating the effects of drought, as well as adaption response for the impact of saltwater encroachment related to global weather change and rises in sea level on the coastal groundwater resources of small island states (e.g. Eastern Caribbean 2009). [2] An analysis in Dhaka city, Bangladesh, establishes that utilization of harvested rainwater can save 11% of public water supply per year and the volume of collected rainwater can serve about 1.5 month in a year without the traditional water supply.

Nowadays, climate is changing abruptly on a daily basis, and global warming is the most significant cause of difficulty worldwide. Given this situation, the green roof has an important role in improving air quality and helping to reduce the unban heat island effect. Green roofs are more durable than conventional roofs and have an important impact in terms of reducing energy costs with natural insulation, reducing urban stormwater runoff, and hence reducing the need for complex and expensive drainage systems [3–6].

Simply explained, a green roof is a vegetated rooftop, which consists of different layers covered with plants over an existing roof structure. The growing medium of plants (soil) is placed on a water proofing membrane so that water cannot percolate through the medium and damage the roof structures. Green roofs allow traditional vegetation without disrupting urban infrastructures. It is more useful compared to alternatives, for its takes up negligible space. There are two main types of green roofs: intensive and extensive. Intensive green roofs have a thicker growing medium (more than 150 mm), usually consisting of planted shrubs, perennial herbs, and grasses, whereas extensive green roofs have a thin substrate layer (less than 150 mm) and contain sedum or lawn [6–8].

The monitoring program for MSMA (Stormwater Management Manual for Malaysia) stormwater management and eco-hydrology project at humid tropic center (HTC) has developed a proposal for the latest cross section for green roof.

The scarcity of fresh drinking water has become the most important problem for human beings [9]. Due to high growth rate of population, rapid urbanization, industrialization, and destruction of green trees, drinking water availability has already decreased worldwide. Among various proposed solutions for water scarcity, roof rainwater harvesting is

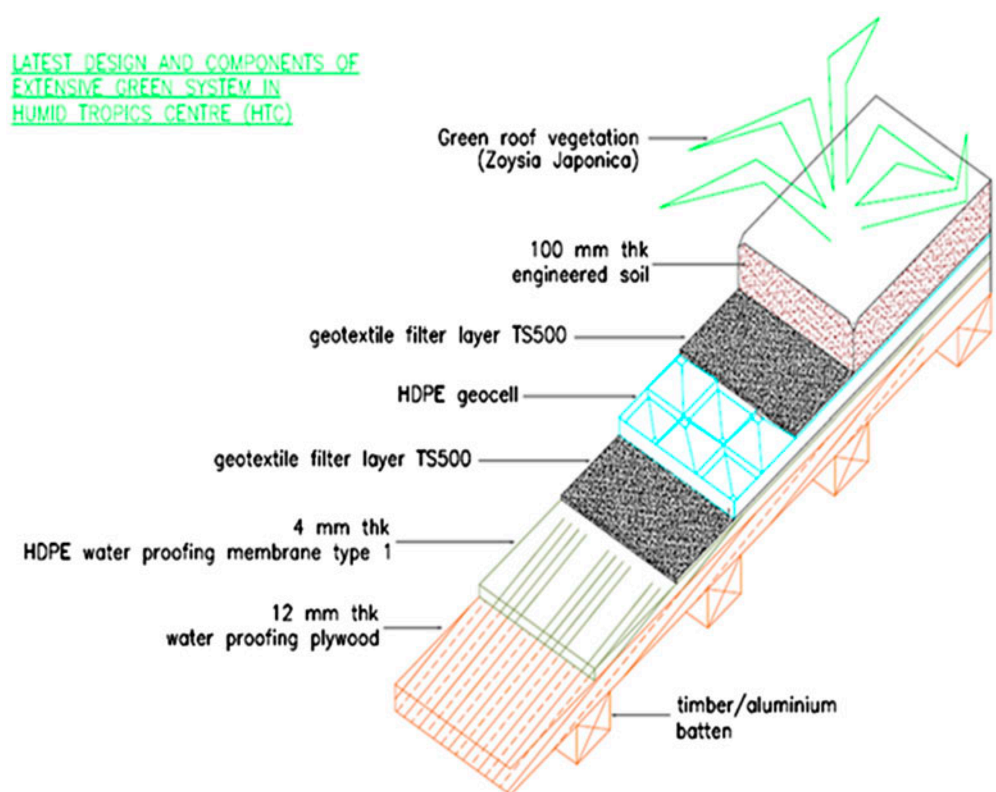

Fig. 1. Latest design and components of extensive green system in HTC.

the best solution for urban areas. It could meet the requirements for the domestic water shortages, reduce urban stormwater runoff, and hence could protect urban areas from flooding [10]. Rainwater harvesting is a sustainable solution for potable water demand in urban developments, because it provides the cleanest water [11,12]. The quality of harvested rainwater basically depends on types of roofing materials and the climatic conditions of the local area, as well as the level of atmospheric pollution [13,14]. Peak discharge can be reduced to 47% by the extensive green roofs for design storms and 26% for actual storms [15].

2. Methodology

The whole study was done in HTC at Kuala Lumpur (Figs. 1–3).

The monitoring program for MSMA stormwater management, eco-hydrology project is performing a study at HTC, Kuala Lumpur, Malaysia. The rainfall intensity is very high in Malaysia, and the country is rapidly urbanizing and industrializing as well. Urban stormwater runoff management becomes very challenging for urban planners and engineers. They are trying to establish the MSMA SME as the best alternatives for providing sustainable management through improving water quality to reuse of stormwater and graywater harvesting so as to meet the growing demand for domestic potable water [16].

Fig. 2. Layer of geotextiles (white sheet) was laid underneath vegetation and soil layer of the green roof system.

Fig. 3. 3,700 standard's sequential base section with 24 wide-mouth, W edge-shaped Polypropylene Bottles with a Capacity of 1,000 ml Each.

The Department of Environment (DOE) of Malaysia has provided Interim National Water Quality Standards (INWQS) and the Water Quality Index (WQI) to compare water quality standards. There are six classes of water quality: I, IIA, IIB, III, IV, and V, which represent descending order of water quality from rivers or streams. Class I is the best quality and needs very minor treatments like filtration/disinfection to reach water quality standards, while class V is the worst and is most harmful to use unless treated properly [17].

The quality of outflow from green roofs mostly depends on proper installation of geotextiles. Yellowish or brownish colored outflow will be generated when geotextiles are not laid underneath the soil layer; but geotextiles are installed properly below the soil layer, where the edge joints of the sheets overlap by at least 30 cm to prevent leakages along the connection points. The outflow produced from that roof will be relatively clean.

Water quality:

- Continuous—sensors; and
- Collection of discrete samples—this is usually undertaken by automatic samplers during rain

Table 1
Monitoring parameters for green roof

Types of monitoring	Parameter	Type of container and minimum sample size
Physical parameters		
	• Temperature	
Chemical parameters		Plastic 2 L
	• Dissolved oxygen (DO) • pH • Conductivity	

events, but occasional grab samples should also be collected in baseflow, as well as during rain events to verify samples collected by automatic samplers.

For water quality monitoring, *Isco*3700 portable samplers have been used for water sampling and multiprobe for *in situ* water quality determination. The water sampling process will be initiated via receiving impulses from the flow module. The impulses will be generated as conditions predefined by the user are met. Again, the volume of samples collected, the total amount of samples collected per storm event, and the intervals between sample collection will be predefined by the user. The water samples stored in the portable sampler will be collected from time-to-time (say, after every storm event) and sent to an accredited laboratory for advanced physical and chemical water quality analysis. The appointed laboratory for testing water quality of the samples is TaliWorks Analytical Laboratory.

A multiprobe is applied in every component as well in order to determine the *in situ* water quality of runoff produced by each component. The parameters that the multiprobe examines are dissolved oxygen (DO), temperature, pH, and hydraulic conductivity. These parameters will be examined by the multiprobe according to the interval predefined by the user (Table 1).

Table 2
Water quality analysis for rainwater harvesting from samples

Date of sampling	Conductivity (μs/cm)	Dissolved oxygen (ppm)	pH	Temperature (℃)
28/01/13	91.638	5.088	6.489	28.439
29/01/13	94.18	5.273	6.21	25.18
30/01/13	102.891	5.179	6.363	25.95
31/01/13	104.545	5.148	6.293	26.93
01/02/13	104.88	5.08	6.419	27.29
02/02/13	107.133	5.12	6.228	29.413
03/02/13	105.973	5.278	6.367	27.00
04/02/13	108.98	4.97	6.221	25.56
05/02/13	107.754	4.775	6.39	24.943
06/02/13	133.78	5.556	6.187	25.759
07/02/13	104.09	5.259	6.184	25.001
09/02/13	86.24	5.579	6.056	26.276
13/02/13	113.924	4.846	7.347	27.006
14/02/13	115.575	4.969	6.616	25.022
18/02/13	102.65	5.258	6.055	25.29
20/02/13	98.218	4.725	6.484	25.65
22/02/13	48.313	6.35	5.41	23.09
25/02/13	90.585	5.857	5.90	25.353
26/02/13	101.74	5.153	5.73	26.787
27/02/13	102.215	4.963	5.86	25.16
28/02/13	101.715	4.755	7.12	26.229
01/03/13	104.215	4.63	6.18	28.677
02/03/13	109.795	5.786	5.858	29.29
03/03/13	111.12	5.023	7.499	27.854
04/03/13	114.489	4.532	5.919	27.22
05/03/13	114.189	4.552	6.095	26.676
08/03/13	116.448	5.177	5.588	25.954
26/03/13	80.43	4.857	6.55	30.285
27/03/13	92.88	4.572	5.744	27.212
28/03/13	92.655	5.267	5.723	27.691
30/03/13	98.985	4.124	5.508	26.419
31/03/13	100.147	4.806	5.725	27.173
01/04/13	87.444	4.446	5.24	27.59
02/04/13	99.278	3.641	5.90	27.905
03/04/13	95.941	5.522	6.118	27.171
04/04/13	98.675	5.119	6.189	26.326
05/04/13	91.684	5.797	5.913	27.577

Table 3
Comparison of water quality with WQI and INWQS for sample collected on 28/01/2013

Parameter	Outlet at 4.30 pm	INWQS	WQI
Conductivity	91.638 µs/cm	Class-I	–
Dissolved oxygen (DO)	5.088 mg/l	Class-IIA	Class-II
pH	6.489	Class-I	Class-II
Temperature	28.439˚C	Class-IIA	–

Table 4
Comparison of water quality with WQI and INWQS for sample collected on 01/02/2013

Parameter	Outlet at 8.30 pm	INWQS	WQI
Conductivity	104.88 µs/cm	Class-I	–
Dissolved oxygen (DO)	5.09 mg/l	Class-IIA	Class-II
pH	6.419	Class-I	Class-II
Temperature	27.29˚C	Class-IIA	–

Table 5
Comparison of water quality with WQI and INWQS for sample collected on 14/02/2013

Parameter	Outlet at 08.45 am	INWQS	WQI
Conductivity	115.757 µs/cm	Class-I	–
Dissolved oxygen (DO)	4.969 mg/l	Class-III	Class-III
pH	6.616	Class-I	Class-I
Temperature	25.012˚C	Class-I	–

Table 6
Comparison of water quality with WQI and INWQS for sample collected on 28/02/2013

Parameter	Outlet at 10.00 pm	INWQS	WQI
Conductivity	101.715 µs/cm	Class- I	–
Dissolved oxygen (DO)	4.755 mg/l	Class-III	Class-III
pH	7.12	Class-I	Class-I
Temperature	28.662˚C	Class-IIA	–

Table 7
Comparison of water quality with WQI and INWQS for sample collected on 01/03/2013

Parameter	Outlet at 1.45 am	INWQS	WQI
Conductivity	104.215 µs/cm	Class-I	–
Dissolved oxygen (DO)	4.63 mg/l	Class-III	Class-III
pH	6.28	Class-IIA	Class-II
Temperature	26.229˚C	Class-IIA	–

Table 8
Comparison of water quality with WQI and INWQS for sample collected on 08/03/2013

Parameter	Outlet at 4.30 am	INWQS	WQI
Conductivity	116.448 µs/cm	Class-I	–
Dissolved oxygen (DO)	5.177 mg/l	Class-IIA	Class-II
pH	5.588	Class-III	Class-III
Temperature	25.954˚C	Class-IIA	–

Table 9
Comparison of water quality with WQI and INWQS for sample collected on 31/03/2013

Parameter	Outlet at 2.45 am	INWQS	WQI
Conductivity	100.147 µs/cm	Class-I	–
Dissolved oxygen (DO)	4.806 mg/l	Class-III	Class-III
pH	5.725	Class-III	Class-III
Temperature	27.17˚C	Class-IIA	–

Table 10
Comparison of water quality with WQI and INWQS for sample collected on 02/04/2013

Parameter	Outlet at 7.00 pm	INWQS	WQI
Conductivity	99.278 µs/cm	Class-I	–
Dissolved oxygen (DO)	3.641 mg/l	Class-III	Class-III
pH	5.90	Class-III	Class-III
Temperature	27.905˚C	Class-IIA	–

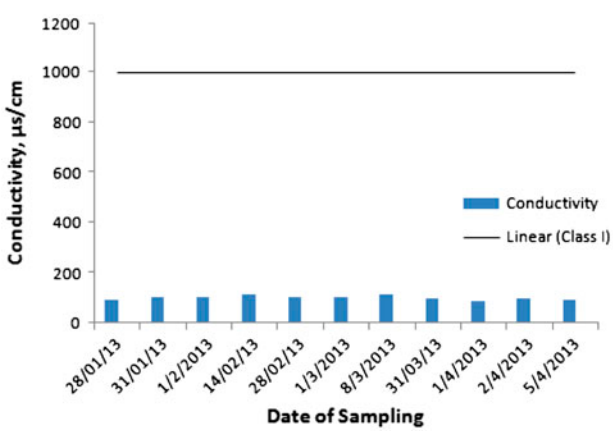

Fig. 4. Comparison of conductivity of samples with INWQ.

3. Results and discussion

Table 2 shows the testing results of the four samples taken in the monitoring session. Each sample will be analyzed and compared with INWQS and DO, and pH will be analyzed with WQI.

As observed in Tables 3–10, the result show that the maximum inlet samples from green roofs are within Classes I and II of INWQS. The results are for samples collected on 28 January 2013 and 01 February 2013. DO concentration is found to be Class III for the sample collected on 14 February 2013. The value of pH is found to be Class III for the sample collected on 08 March 2013. For the samples collected on 31 March 2013 and 02 April 2013, both DO and pH value are found to be Class III.

Figs. 4–7 illustrate the comparison of conductivity, DO, pH value, and temperature of samples with INWQS. It shows that conductivity values are always within Class I. DO is found to be between Classes I and II. Low concentration of DO in the outflow means that the green roof system incurs substances which can deplete the amount of oxygen dissolved into the water passing through the system. The maximum pH value obtained in the outlet is found to be less than the value of Class I, and some values between Classes I and II. The observed pH values are more acidic than

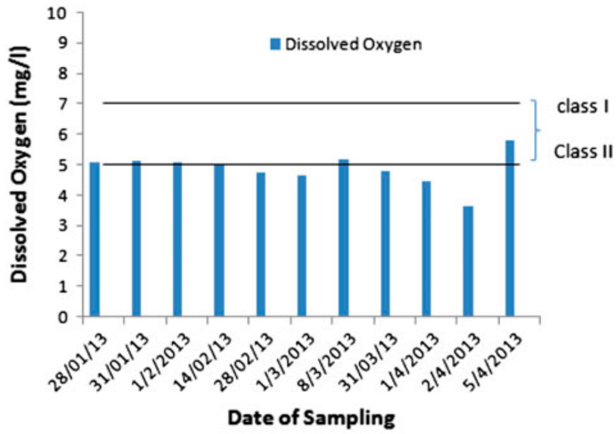

Fig. 5. Comparison of DO with INWQS.

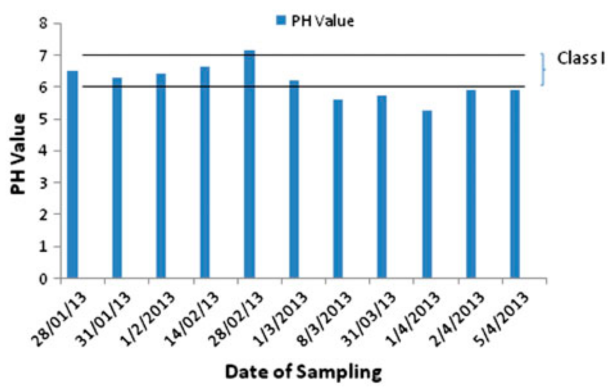

Fig. 6. Comparison of pH value with INWQS.

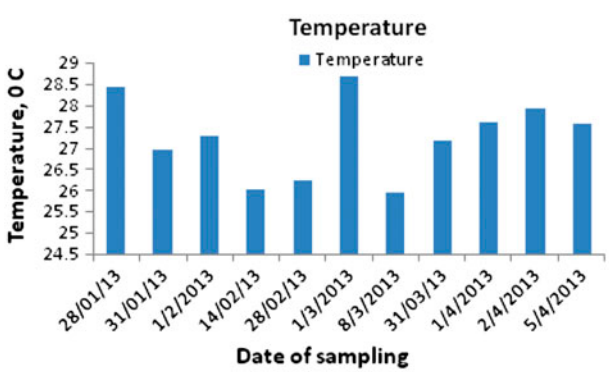

Fig. 7. Variation for temperature.

the standard value. For temperature, all values are within the standard limit meaning that green roofs control internal heat absorption.

4. Conclusion

The above performance of an extensive green roof system in HTC is promising under local tropical climate. The simulation conducted in this study indicates the following:

(1) The rainwater harvesting from green roofs in HTC has an average water quality in comparison to INWQS and WQI.
(2) Electric conductivity parameter always having an excellent value of Class I.
(3) Some preliminary treatments like filtration and disinfection may need to be applied to reach the standard value of DO and pH for those containing the value of Class II.
(4) The non-treated rainwater from green roofs can be used for flushing toilets and watering gardens.
(5) Green roofs can control the indoor temperature as it acts as a heat absorbent and can keep temperatures within the normal level.

The general sense about green roofs is that they release additional solids into the runoff, as the substrate layers are made of soil, sand, and humus. But the geotextile layer which lies under the substrate layer may reduce the total suspended solids into the outlet, hence reducing turbidity. The other water quality parameter: biological oxygen demand, chemical oxygen demand, total suspended solid, turbidity, ammoniacal nitrogen (NH_3-N), and PO_4 should be taken into consideration for further study. Another analysis can be made on the treatment required for green roof harvested rainwater to reach drinking water quality standards.

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