Monitoring on The Quality and Quantity of DIY Rainwater Harvesting System

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Abstract. Rainwater harvesting is an alternative sources of water supply and can be used for potable and non-potable uses. It could helps to store treated rainwater for more beneficial use and also for flood mitigation. Sustainable approach for flooding problem reduction in urban areas is by slowing down the rate of surface runoff flows at source by providing more storage area/tank. In order to understand the performance of a rainwater harvesting system (RWH), a preliminary monitoring on a “do it yourself” (DIY) RWH model with additional first-flush strategy for water quality treatment was done. The main concept behind first flush diversion is to prevent initial polluted rainwater from entering the storage tank. Based on seven rainfall events observed in Parit Raja, both quality and quantity of the rainfalls were analysed. For rainwater quality, the samples from first flush diverter and storage tank were taken to understand their performance based on pH, dissolved oxygen (DO), turbidity, total dissolved solid (TDS), total suspended solid (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) parameters. While for rainwater quantity, hydrograph analysis were done based on the performance of total rainfall and runoff, peak flow of rainfall and runoff; and delayed time parameters. Based on Interim National Water Quality Standard (INWQS) and National Drinking Water Quality Standard (NDWQS), first flush diverter apparently helps on water quality improvement in storage tanks when pH, DO, TDS, TSS and turbidity were classified as Class I (INWQS) and is allowable for drinking; but BOD and COD parameters were classified as Class III (INWQS). Hence, it has potential to be used as potable usage but will need extensive treatment to reduce its poor microbial quality. Based on the maximum observed rainfall event which had total volume of 3195.5 liter, had peakflow reduction from 0.00071 m³/s to 0.00034 m³/s and delayed runoff between 5 and 10 minutes after rainfall started. It concludes that the performance of water retention could be due to total rainfall and the tank capacity. Therefore, RWH has a potential to be used as potable use and at the same time it also has a potential to reduce local urban flooding.

Keywords: Rainwater quality, rainwater quantity, first flush strategy, portable use, water supply.

1. Introduction
Malaysia is a country with an equatorial climate that characterized by hot and humid throughout the year of two monsoon seasons. With regions that consist variety of topographical combinations such as floodplains, highlands, lowlands and coastal areas, Malaysia is typically receives around 2000 mm to 4000 mm rainfall annually [1,2]. However, with continuous and frequent intense rainfalls occurrence may causes flooding problems especially in urban areas. Various approaches have been implemented by authorities to reduce and prevent flooding problems such as drainage and irrigation system improvement based on Sustainable Urban...
Drainage System (SUDS). Rainwater harvesting (RWH) system is one of the SUDS structure that use for home/building rainwater reservoirs that provides more storage at source, hence surface runoff flow can be reduced. Apart from water control at source, RWH also has ability to be retrofitted around the existing housing areas and buildings at any time needed.

According to [3], the increase in impervious surfaces, including rooftops and pavement such as roads, driveways, parking lots and many more, the decreases the amount of water that soaks into the ground, or infiltrates and increases the amount of surface runoff. The excessive runoff will carries contaminants directly into water bodies because of less infiltration, peak flows of storm water runoff becomes larger and will arrive earlier, hence the magnitude of urban floods will increase [3] On the contrary, when Malaysia land is blessed with higher intense rainfall, without proper management to handle the plentiful water, rainwater will be wasted, downstream area will be flooded but ironically, clean water supply is scarce.

Growth of population and expansion in urbanization, industrialization and irrigated agricultural is imposing growing demand and pressure on water resource [4]. A new development of water resource from rainwater is very important to make sure there is no water shortage in the future [4]. The RWH system is a simple collection of water from the roof areas where the rain falls and the utilization of rainwater may involves for domestic and the agriculture purpose [5]. With estimation of average annual rainfall at 3000 mm or 990 billion m$^3$ over Malaysian land, 566 billion m$^3$ is estimated to becomes surface runoff. Hence, before water shortage becomes threat and crisis for country, further understanding for promoting and encouraging public to implement the system need to be done.

2. Material And Methods

2.1 Components of DIY rainwater harvesting system

Rainwater harvesting components are commonly consists of roof, gutter, downspout, first-flush diverter, filter and storage tank [6] (Figure 1). The 7 m × 5 m roof is a catchment area for RWH system but roof also could collect dust and other debris such as leaves, bird dropping and roof corrosion on them during dry days. The quality of drinking water can be much improved if this debris is not allowed to enter the storage tank [7]. Second component is a 7 m gutter which has function to catch the rain from the roof catchment surface and transport it to the cistern [8]. Third component of rainwater harvesting system is downspouts which brings rainwater from a gutter. The downspouts using 80 mm of polyvinyl chloride (PVC) pipelines were used to carry rainwater from the catchment area to storage tanks (Figure 1).

Fourth component is a first flush diverter which use to improve the quality of roof runoff prior to storage. Two bottles are holed at the bottom and being glued together and it is equivalent to 1800 ml of volume when its full of water (Figure 2). The DIY glued bottles acts as first-flush diverter which use to collect the first flush of contaminated rainwater especially after long period of dry days. As the water rises in the diverter, the plastic ball will stop the next rainwater from roof from entering the first flush diverter. The following rainwater will continue to flow to the last component which is storage tank. Storage tank will collect and store the clean rainwater from roof. Storage can be aboveground or underground, and consists of barrels, tanks, cisterns, or bladders. In Malaysia, a standard size of tank is 1 m$^3$ for every 100 m$^2$ roof catchment area [6]. Therefore, a tank with 0.385 m$^3$ in size is suitable for 38.5 m$^2$ of roof area. However, in this study, a storage box with 0.045 m$^3$ in size was used as a tank. The size of the tank used was just for this study only with assumption that if the small storage capacity of water will results in good reduction and delaying runoff, hence the larger tank storage would do more effectively.
Table 1 shows the material used to build a DIY rainwater harvesting with first flush diverter. All material is available to be found in market.

Table 1. Material and quantity used in DIY rainwater harvesting system.

| No | Material                  | Quantity |
|----|---------------------------|----------|
| 1  | Gutter                    | 1        |
| 2  | 80 mm diameter PVC        | 1        |
| 3  | 20 mm diameter PVC        | 1        |
| 4  | Bracket                   | 3        |
| 5  | PVC T ‘20 mm’             | 1        |
| 6  | Glue                      | 1        |
| 7  | Bottle                    | 2        |
| 8  | Storage box               | 1        |

3. Data Collection

For rainfall data collection, a manual DIY raingauge was used. Point rainfalls were measured using this raingauge by measuring the cumulative rainfalls in this bottle, and was installed adjacent to the roof catchment. Whilst for storage runoff data, a DIY weir at side of tank was made (Figure 3) and the water level of overflow rainwater were measured. Total volume of retained rainwater in tank before it started to overflow through the weir is 15.48 liter. The outflow discharge, Q is calculated based on the equation of [9]:

\[ Q = \frac{2}{3} C_d \sqrt{2ghLH_1^{\frac{3}{2}}} \]  

(1)

Where \( C_d \) is coefficient of discharge, \( L \) is spanning length of rectangular weir and \( H_1 \) is the depth of flow above the weir crest. The variation of \( C_d \) for rectangular sharp-crested weir is given by Rehbock formula [9]:

\[ C_d = 0.611 + 0.08 \frac{H_1}{P} \]  

(2)

Where \( P \) is height of the weir and the formula is valid only for \( H_1/P \leq 5.0 \). During rainfall events, both data rainfall and runoff were manually recorded at 5 minutes interval.
For rainwater quality, during rainfall events, samples from the first flush diverter and storage tank were taken to be tested on the following parameters: pH, dissolved oxygen (DO), turbidity, total dissolved solid (TDS), total suspended solid (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) (Table 2). The analysed parameters were then compared to Interim National Water Quality Standard [10] and National Drinking Water Quality Standard [11]. The RWH system is installed in housing area at Jalan Parit Hj Rais, Parit Raja Batu Pahat. The housing area is located near to oil palm plantations and factories. In agricultural areas, rainwater is expected to have higher concentration of nitrates due to fertilizer residue in the atmosphere [12]. However, limited parameters were tested due to limitation of reagent available.

| Parameter                        | Equipment                                      |
|----------------------------------|------------------------------------------------|
| pH                               | pH Meter                                      |
| Dissolved oxygen                 | DO meter                                      |
| Turbidity test                   | DR/4000 1-Inch Cell Adapter                  |
| Total Dissolved Solid (TDS)      | TDS meter                                     |
| Total Suspended Solid (TSS)      | DR 6000                                       |
| Chemical Oxygen Demand (COD)     | DRB200 reactor                                |
| Biochemical Oxygen Demand (BOD)  | DO meter                                      |

4. Results And Discussions
Both monitoring were not always available at the same time frame due to limitation on the laboratory usage. Water samples for rainwater quality were taken on 19/3/15, 22/3/15, 31/3/15, 1/4/15 and 12/4/15; while for rainwater quantity observation were taken on 29/3/15, 31/3/15, 1/4/15, 4/4/15 and 12/4/15 rainfall events.

4.1 Monitoring on rainwater quality
For each rainfall events, the average from three sample readings were taken. From observations, there were 10 days of dry days before rainfall event on 19/3/15 started, and it takes 3 days of dry days prior to rainfall events on 22/3/15. The next rainfalls were a continuous rainfall events from 30/3/15 to 31/3/15. After 8 days of dry days, another rainfall event occured on 12/4/15 (Table 3). The categorization of total rainfall (in mm) are as follows; < 25.4 mm (small storms), 25.4-76.2 mm (medium storms) and > 76.2 mm (large storms).

Generally, all pH readings in first flush samples are slightly acidic than storage tank (Table 3 & Table 4). However, all samples were fall between 6.5 and 8.5 which is in neutral condition and were classified as Class 1 by INQWS and acceptable values for drinking water. Sample 4 proved that with frequent rainfall, rainwater will flushed away all the air pollutant as stated by [13], the pH of rainfall would be 7.0 if there were nothing else in the air.

| Sample | Date of sampling | Type of storms |
|--------|------------------|----------------|
| 1      | 19/3/15          | Small          |
| 2      | 22/3/15          | Small          |
| 3      | 29/3/15          | Small          |
| 4      | 31/3/15          | Medium         |
| 5      | 1/4/15           | Large          |
| 6      | 4/4/15           | Small          |
| 7      | 12/4/15          | Small          |

The concentration readings for DO for both components also shows that the rainwater have an adequate supply of dissolved oxygen to be classified as Class I. For turbidity, 5 NTU is a standard for drinking water quality, but for our readings in first flush exposed that, it is still acceptable for raw water quality which are less than 1000 NTU. After treatment, the turbidity concentrations are better in storage tank and its even better if it has larger rainfalls. TDS and TSS also shows good improvement after treatment to be classified then as Class I for samples in storage tank and acceptable for drinking water standard even for TDS and TSS in first flush samples.
Table 4. Comparison from average reading of first flush samples.

| Test           | First Flush Sample |  |
|----------------|--------------------|--
| (pH)           | 6.5                | 6.54   | 6.56   | 6.90   | 6.51   | Class I  |
| DO (mg/L)      | 7.31               | 7.92   | 7.68   | 7.90   | 7.85   | Class I  |
| Turbidity (NTU)| 44.0               | 22.5   | 39.3   | 11.2   | 35.2   | Class IIA|
| TDS (mg/L)     | 138                | 136    | 105    | 58.7   | 104    | Class I  |
| TSS (mg/L)     | 48.0               | 45.0   | 30.3   | 15.0   | 31.3   | Class IIA|
| COD (mg/L)     | 191                | 175    | 125    | 68.6   | 103    | Class I  |
| BOD (mg/L)     | 16                 | 14     | 14.3   | 13.4   | 13.6   | Class V  |

However, the concentrations of COD and BOD from the samples are quite high and could not be accepted as raw water quality which supposed to have acceptable values around 10 mg/L and 6 mg/L, respectively. Hence, based on INWQS, the concentrations of both COD and BOD can be classified as Class V for samples in first flush diverter, and improved to Class III in storage tank samples.

The monitoring on rainwater quality exposed the information that, for RWH system can be used as drinking water, but extensive treatment for COD and BOD are needed.

Table 5 Comparison from average reading of storage tank samples.

| Test           | Storage Tank Sample |  |
|----------------|---------------------|--
| (pH)           | 6.54                | 6.61   | 6.87   | 7.21   | 6.73   | Class I  |
| DO (mg/L)      | 7.05                | 7.60   | 7.45   | 7.76   | 7.72   | Class I  |
| Turbidity (NTU)| 3.1                 | 2.5    | 2.4    | 0.4    | 2.2    | Class I  |
| TDS (mg/L)     | 44.5                | 48.2   | 36.3   | 6.60   | 23.7   | Class I  |
| TSS (mg/L)     | 2.0                 | 1.0    | 1.0    | 0.7    | 1.0    | Class I  |
| COD (mg/L)     | 50                  | 34.2   | 46     | 25.3   | 37.3   | Class III|
| BOD (mg/L)     | 5.86                | 2.07   | 5.44   | 1.67   | 4.3    | Class III|

4.2 Monitoring on rainwater quantity

For each rainfall events, the quantity of rainfall were recorded when every rainfall started until it stopped, in order to observe the rise in water level in the storage tank. All the water will flows into gutter, downspout and into the 1800 ml of first flush diverter, prior to fullfill the 15.48 liter tank capacity. Overall, total volume of 17.28 liter of rainwater will be retained for every rainfall occurrence, if the tank can be emptied at every time after rainfall. Hence, for this DIY system, from the observation of each rainfall (Figure 4), it is expected that for medium and larger storm, it will typically takes between 5 and 10 minutes to fullfill the 17.28 liter; at least between 15 and 20 minutes for medium rainfall that weighted almost close to larger values (Figure 4(b) and Figure 4 (c)). It can be varied for medium and small rainfalls to fullfill the 17.28 liter where it will depends on the characteristis of the storm; the types and durations. For example small rainfall on 29/3/15 has 10 mm of rainfall (duration of 170 minutes) takes about 115 minutes to fill in the 17.28 liters, while for rainfall on 4/4/15 with 17 mm (duration of 140 minutes) needs only 50 minutes to fullfill the 17.28 liters. However, small rainfall on 12/4/15 which has 20 mm of total rainfall within duration of 115 minutes, only needs between 15-20 minutes to fills in the storage tank (Figure 4(e)).
The values of inflow discharge, $Q$ is measured by rainfall data collected using the DIY raingauge. Based on the area of roof catchment, the point rainfalls were then converted into volume in m$^3$. At the same time, water levels of overflowed rainwater via rectangular weir are measured and then being converted into the outflow discharge using Equation (1).

Based on the hydrographs analyses (Figure 4), it can be seen that the total volume of the outflow discharges were reduced and retained, and it is obviously known that total retained volume will be the same volume provided by the first flush diverter and tank capacity which is 17.28 liter. It applicable for all types of

Figure 4. (a) to (e): The inflow and outflow of each monitored rainfall for rainwater quantity.
rainfall events including rainfall on 1/4/15 that produced 3195.5 liter of total rainfall volume. However, for this large rainfall type, with small tank capacity like the DIY RWH, could delays runoff to start after rainfall started between 5-10 minutes, and reduced the peakflow from 0.00071 m$^3$/s to 0.00034 m$^3$/s would gives significant impacts on the flow at the downstream drainage area. Hence, with bigger tank capacity, the delays and the volume of outflow discharge could perform better than the DIY RWH.

5. Conclusions
Based on simple preliminary monitoring on the quality and quantity of ‘do it yourself’ rainwater harvesting system, it is observed that RWH system can be performed as the best storage structure to control water at source for tropical country with high average rainfalls like Malaysia. Although RWH concept has been implemented since few thousand years ago in many countries like USA, China, Japan [4] and few more including Malaysia, but the use of RWH system at most of the time typically highlighted for water supply purposes only. Therefore understanding on rainwater quality is essential for water supply especially for drinking water. However, in this study, the concentration of some parameters like water hardness (dissolved calcium and dissolved magnesium), iron, nitrates, chlorides, sulphates and conductivity [14], parameters that originate from atmospheric sources that impact the waterbodies by rain [15] such as sulfur compound, nitrogen compounds, pesticides, mercury and other toxics are not extensively measured; considering that the location of RWH system is in the agricultural and industrial area. Still, this study highlights that the rainwater is in neutral condition, however the rainwater contained higher concentration of COD and BOD represents the quality of rainwater in the area are having inadequate oxygen available and having microbial activities on the roof catchment site, respectively; and the variety results of parameters concentration could depends on the weather, geography location and activities around the location area.

RWH system also has a role as retention and detention structure although it could not stand alone without any supporting structures to mitigate flood. Still, if one single small storage tank like DIY RWH system can retained, reduced and delayed small portion of the large storm at one particular house; with another i.e 10 houses and their 10 small storage tanks, more volumes can be retained, detained and delayed for a residential area. Larger storage of tank capacity would do better and less surface runoff would be produced at downstream areas of urban areas. The retained/stored water would then be used as an alternative source for water supply for each house, and indirectly could reduce the utility bills for the houses.

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