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Water Quality of Rooftop Rainwater Harvesting System (MyRAWAS)

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Abstract. Prolonged drought, population growth and water demand for various purposes have increased the water scarcity issue. To overcome this issue, a rainwater harvesting system can be utilized as an alternative for clean water supply. A rainwater harvesting system is a method of collecting rainwater from man-made surfaces such as rooftops and constructed surfaces and can be used for various sectors including household, agricultural and commercial. This study was conducted to determine the quality of rainwater harvested collected directly from rooftop. The quality of the rooftop rainwater was taken in three consecutive months and the water quality for before and after treatment was measured and compared. Commercial activated carbon was used to treat the rainwater obtained from the rooftop. The water quality was compared with the Water Quality Index (WQI) and the National Water Quality Standards (NWQS). The parameters involved are pH, temperature, conductivity, dissolved oxygen (DO), total suspended solids (TSS), ammoniacal nitrogen (NH_3-N), biochemical oxygen demand (BOD), chemical oxygen demand (COD), *E.coli* and total coliform bacteria. The results showed that the total value of WQI before and after treatment was 86.3 ± 8.963 and 87.6±2.081, respectively. Positive correlations were found for parameter NH_3-N, COD and pH, while paired T-test showed a significant in the COD and the presence of bacteria. Total Coliform is still at a safe level by NWQS with the average value and the standard deviation for before and after treatment were 38.11 ± 13.960 cfu/ml and 10.33 ± 6.671 cfu/ml, respectively.

Keywords: Rainwater harvesting system, Water quality, Sustainable water resource, MyRAWAS, Malaysia

Track Name: Advanced Technology and Renewable Energy

1. Introduction

Rapid urbanization causes a series of environmental problems such as clean water and water resource shortages, deteriorating urban water quality, inadequate water infrastructure, and frequent flood disaster [1]. Clean water supply crisis definitely gives a huge impact on our daily life. Therefore, the probability of occurrence of water crisis that will bring disaster to the people and the national economy should be taken more seriously. The population has increased for the last six years with a rate of 3.5 per cent per annum and this scenario requires an increase of about 10 % of water reserve capacity to meet the needs of users at peak times and to accelerate the recovery period of the water supply disruptions [2]. Some measures should be taken to overcome the water crisis that includes aspects of the present and future mitigation. In order to help overcoming the water crisis in the future, a rainwater harvesting system and its implementation has been proposed as a part of an alternative solution to the dependency of the existing water supply. In addition, a rainwater harvesting system is seen as an alternative source of which is based on green technology that is environmentally friendly and sustainable [3].

A rainwater harvesting system is a method of collecting rainwater from man-made surfaces such as rooftops and constructed area which can be used for various sectors including household, agricultural and commercial. This collection system is feasible and an educational way to reduce potable water use. Precipitation is one of the sources of water and can be obtained from the natural water cycle that continues through the process of evaporation and transpiration [3]. Rainwater harvesting system is suitable to be implemented in Malaysia because Malaysia receives high rainfall and is in the equatorial climate, which is hot and humid. Rainfall of 3000 mm per year is estimated to be equivalent to the total annual water resources of about 990 billion m^3 [4]. Therefore, the rainwater harvesting system should be implemented to resolve the water crisis in the country. However, the aspects of water quality need to be considered in the use of rainwater to ensure the quality of the water is in a class Water Quality Index (WQI) which is suitable and safe for use by humans and should be according to the standards of WQI, Department of Environment.

In addition, water quality should also be compared with the National Water Quality Standards (NWQS) drafted by the Department of Environment, Malaysia. Rainwater harvesting system provides many benefits to all aspects of the consumer and environment. Among the benefits that can be gained is the ability to reduce the use of available fresh water to a more important use like for food and beverages. Water consumption bills can also be reduced due to saving fresh water in everyday life. Furthermore, the system can slow down water runoff and may overcome the problem of clean water supply, especially in rural areas.

Currently, universities in Malaysia are experiencing clean water supply crisis especially in residential colleges [5]. Therefore, various alternatives have been introduced to address this problem and rainwater harvesting is one of the initiatives that has been introduced because the construction of rainwater harvesting systems have no negative impact and does not pollute the environment. Ungku Omar College (KUO) is a college that affected the most by the crisis among the colleges in the Universiti Kebangsaan Malaysia (UKM) and MyRAWAS project is a pilot project in which was built in KUO. High rainfall in Malaysia makes it a country appropriate for rainwater harvesting system. The quality of rainwater collected through MyRAWAS system should be monitored periodically to ensure the cleanliness and safety of the water for the use of students and residents of the college. Thus, the study of water quality including chemical, physical and biological aspects needs to be done consistently. This study aimed to determine the quality of harvested rainwater before and after the water treatment by using the WQI for the parameters of physico-chemical properties. In addition, this study was conducted to evaluate the presence of bacteria in the water based on biological parameters according to the NWQS. Field sampling was conducted in November 2015, December 2015 and January 2016.

2. Materials and Method

2.1. Sampling and study area

Rainwater harvesting system (MyRAWAS) was built between student's residence of Ungku Omar College building (K8M and K8K) as shown in Figure 1. PVC pipes were used to connect the drainage holes for rainwater collection tank, before flowing to the treatment process. Environmentally friendly method was used for rainwater harvesting system consisting of gravel, sand and activated carbon. Rainwater that has been through the treatment process was connected to the storage tank.

Sampling was done three times in November 2015, December 2015 and January 2016. The sampling was carried out in two places, drainage channel that connects the roof to the roof gutter and from the channel where rainwater harvesting treatment system was done. Each sampling was replicated three times to get a more accurate and precise reading. All parameters were analyzed in comparison with the Water Quality Index (WQI) and the National Air Quality Standards (NWQS).

Figure 1. MyRAWAS system

2.2. Sample preparation

All bottles except for the BOD and Schott bottles used prior sampling were soaked for 24 hours with 10 % nitric acid solution, rinsed with distilled water and dried. The collected water samples were preserved to prevent any biological or chemical changes that can alter the composition of real water samples. Table 1 shows the methods and the maximum preservation of water samples for each parameter.

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Table 1. Preparation of samples for ex situ parameter analysis.

	Bottle	Preservation method	Preservation period
TSS	Polyethylene	Stored at 4 ℃	7 days
NH_3-N	Polyethylene	Stored at 4 ℃	28 days
COD	Polyethylene	Stored at 4 ℃	28 days
BOD	Dark glass	Stored at 4 ℃	48 days
E. coli bacteria	Schott	Stored at 4 ℃	6 hours
Total coliform	Schott	Stored at 4 ℃	6 hours

Source: APHA (2017)

2.3. In situ and ex situ measurement

The in-situ parameters involved for the water quality measurement are temperature, pH, conductivity and dissolved oxygen (DO). These parameters are less stable and highly dependent on environmental conditions during measurement [6]. Determination of these parameters was done using the YSI 556 multiparameter on site and the readings were recorded. Ex-situ measurements conducted in the laboratory involved physico-chemical parameters and biological parameters. Table 2 shows the methods and equipment / materials used in the analysis of ex-situ parameters.

Table 2. Methods and instruments used for ex situ parameter.

	Method	Instrument
TSS (mg/L)	Gravimetric	Vacuum pump
NH_3-N (mg/L)	Nessler	Spektrofotometer HACH DR/2010
COD (mg/L)	Digestion and calorimetry determination	Spektrofotometer HACH DR/2010
BOD (mg/L)	$(DO_{initial} – DO_{final})$	YSI 5000 dissolved oxygen meter
E. coli bacteria	Membrane filtration	Eosin methylene blue
Total coliform	Membrane filtration	Eosin methylene blue

2.4. Total suspended solid

Determination of total suspended solids (TSS) has been carried out using glass fibre filter paper with pore size of 0.45ɳm. The filter paper was first weighted (B). After filtering the water samples using vacuum pump, the filter paper was dried in the oven at 103 – 105 ˚C and weighted (A). Equation 1 was used for the determination of TSS.

$$\text{Total suspended solids (mg/L)} = (A-B)/V \times 1000 \text{ mL} \quad (1)$$

Where,
A = Weight of filter paper after filtration (weight of filter paper + dried residue), mg
B = Weight of filter paper before filtration (weight of filter paper), mg
V = Volume of filtered water sample, mL

2.5. Ammoniacal-nitrogen
Determination of ammonia-nitrogen (NH_3-N) concentrations was obtained using Nessler's Reagent [6]. Both the samples were shaken to make sure the samples were mixed well. 1 ml of Nessler's reagent was added to both samples and was shaken daily. Analysis was first carried out with deionised water (blank solution) followed by water samples. All sample cells were wiped clean in advance to avoid light reflection irregularities [7]. The samples were measured using wavelengths of 380 and 425 nm on a HACH DR / 2010 spectrophotometer. Water samples that turned yellow colour shows the presence of NH_3-N.

2.6. Chemical oxygen demand
Determination of chemical oxygen demand (COD) was performed with a tube in the 45 ℃ condition, using HACH 2021 method. The prepared sample was mixed with COD reagent and shaken. The water and blank sample solutions were heated using a Model 456000 COD Reactor with a strong oxidizing agent, such as potassium dichromate for two hours at 150 ℃. Water solution and blank samples were then cooled at a temperature of 20 ˚C up to room temperature for 20 minutes. Then, analysis was carried out and all sample cells were wiped clean to avoid light reflection irregularities [7] before measured using wavelengths of 435 and 420 nm on a spectrophotometer HACH DR/2010.

2.7. Biochemical oxygen demand
During sampling, dissolved oxygen (DO) meter YSI 5000 was used and the initial value was recorded for $DO_{initial}$ reading (Equation 2). Then, the water samples were stored in the dark glass bottles and covered immediately after sampling. The water samples were incubated for five days at a temperature of 18℃ and stored in a place that was not exposed to the sunlight in order to prevent any biological or chemical changes that can alter the composition of real water samples. Using the same method, reading on the fifth day of all samples were recorded.

$$BOD_5 = DO_{initial} \text{ (reading on the first day)} - DO_{final} \text{ (reading on the fifth day)} \quad (2)$$

2.8. E. coli bacteria and total coliform
Determination of *E. coli* and total coliform bacteria was done by using a sample of 1000 ml of water using the schott bottle, sterilized beforehand. Before the analysis, the room was made to be clean to avoid the presence of bacteria because the environment may affect the amount of bacteria in the water samples [8]. The instruments and apparatus were also sterilized. Cellulose acetate membrane filters were inserted into a petri dish containing eosin methylene blue nutrient with no air bubbles. Petri dishes were incubated for 22 hours ± 2 at a temperature of 35ºC and calculation was made after completing this step. The *E. coli* bacteria was determined by counting the metallic green colonies while the total coliform colonies appeared not colored or bright purple. The colonies of both biological parameters were calculated based on Equation 3 and the unit is cfu (Colony Forming Unit) [6].

$$\textit{E. coli} \text{ (100 ml)} = (100 \text{ x total of } \textit{E. coli} \text{ colony})/\text{Volume of filtered water sample (mL)} \quad (3)$$

2.9. Water quality index
Classification of water quality before and after treatment of rainwater harvesting system was based on the WQI and by using Equation 4. Classification of physico-chemical parameters and biological sampling for both treatments was determined based on the National Air Quality Standards (NWQS).

$$WQI = 0.22 (siDO) + 0.19 (siBOD) + 0.16 (siCOD) + 0.15 (siNH_3\text{-}N) + 0.16 (siTSS) + 0.12 (sipH) \quad (4)$$

*si=subindex

2.10. Statistical analysis

Correlation test was used to determine the correlation between physico-chemical parameters for both sampling. T-paired test was also used to determine the difference between the water quality before and after rainwater harvesting system. The statistical analysis was run using SPSS software.

3. Results and Discussion

3.1. Total suspended solid

The TSS readings before and after treatment were 0.12 ± 0.07 mg/L and 0.07 ± 0.05 mg/L, respectively, and both parameters were in class I in WQI (Figure 3). TSS values at pre-treatment sampling were higher than after treatment. This is because the water collected directly from the roof contains sediments, dirt, dry foliage and animal faeces that are most likely to be collected and accumulated on the roof due to the uncovered roof area, and wind factors that contribute to the TSS content for sampling before the treatment. While the TSS value for the second sampling was lower due to the closed tank which does not allow any sediments and debris accumulated in the tank. Some of the factors that can influence TSS readings include wet and dry seasons, water turbulence caused by the wind and economic activities, as well as human settlement. High TSS content can cause higher turbidity that affects physical properties of water [9].

3.2. Ammoniacal-nitrogen

NH_3-N readings before and after treatment were 0.22 ± 0.28 mg/L and 0.04 ± 0.05 mg/L, respectively, and both parameters were in class I. NH_3-N consists of nitrite, nitrate, organic nitrogen, nitrogen gas and organic ammonia nitrogen which usually exists in living organisms [10]. The NH_3-N test is very important in the measurement of water quality because the presence of the nitrogen element can affect the oxygen level in the water. Water with a high content of organic nitrogen and NH_3-N is considered unsafe because it is toxic to the living organisms and may cause high irritation to human skin. The main sources that contribute to the presence of NH_3-N are animal faeces, cleaning agents, solvents or sewage materials. NH_3-N values were higher for pre-treatment sampling than after treatment, as shown in Figure 3. Compared to enclosed tanks and exposed roofs, it clearly shows that roofs are more exposed to environments that contribute to higher NH_3-N concentrations. In addition, the decomposition process by fungi and bacteria can also increase ammonia concentrations [11].

3.3. Chemical oxygen demand

The COD value before treatment was 13.67 ± 13.23 mg/L (class II), whereas after treatment was 2.0 ± 1.12 mg/L (class I). COD measurement is important to determine the amount of oxygen required by oxidizing agents in the process of oxidizing substances to water, ammonia and carbon dioxide chemically [1]. COD values increase in parallel with increasing concentrations of organic matter in water [12]. The COD is used to determine the level of water pollution caused by organic compounds that did not undergo biological decomposition [13].

3.4. Biochemical oxygen demand

The BOD parameters for before and after treatments were in class II and their values were 1.09 ± 1.16 mg/L and 1.33 ± 0.22 mg/L, respectively. BOD test was conducted to determine the level of water pollution and the presence of microorganisms involved in the process of decomposition of organic matter and the amount of dissolved oxygen to oxidize organic matter in water, which leads to an increase in the concentration of BOD [14]. The BOD parameter correlated with DO (0.63) and showed the relationship between each other. This implies that the higher the BOD, the lower the DO of the water body.

3.5. pH

The pH values before and after treatments were both in class II and their values were 6.56 ± 0.34 and 6.61 ± 0.25, respectively. Carbon dioxide found in the atmosphere dissolved in rainwater droplets and forms a very weak carbonic acid [15]. The acids then precipitate on rainwater and cause the water to be acidic. There is a relationship between NH_3-N and pH parameters, the lower the NH_3-N, the better the pH of the water body. A high pH value can cause toxicity to water due to the high ammonia content, while if it is too low, it can cause acidity to the water. The normal pH for clean water is in the range of 5-7.

3.6. Dissolved oxygen

The DO values before and after treatments were in class II with 68.18 ± 20.45 % and 54.40 ± 7.21 %, respectively. The values in unit are shown in Figure 3. Organic matters found in domestic wastes undergo an oxidation process by microorganisms and this process requires oxygen which causes the DO content in the water to be low [1,16].

The positive correlation with the value of R^2 equivalent to 1 was found for NH_3-N, COD and pH parameters. Paired T-test showed significant value ($p < 0.05$), where there was a difference in values before and after rainwater treatment for COD (0.03) with the presence of bacteria.

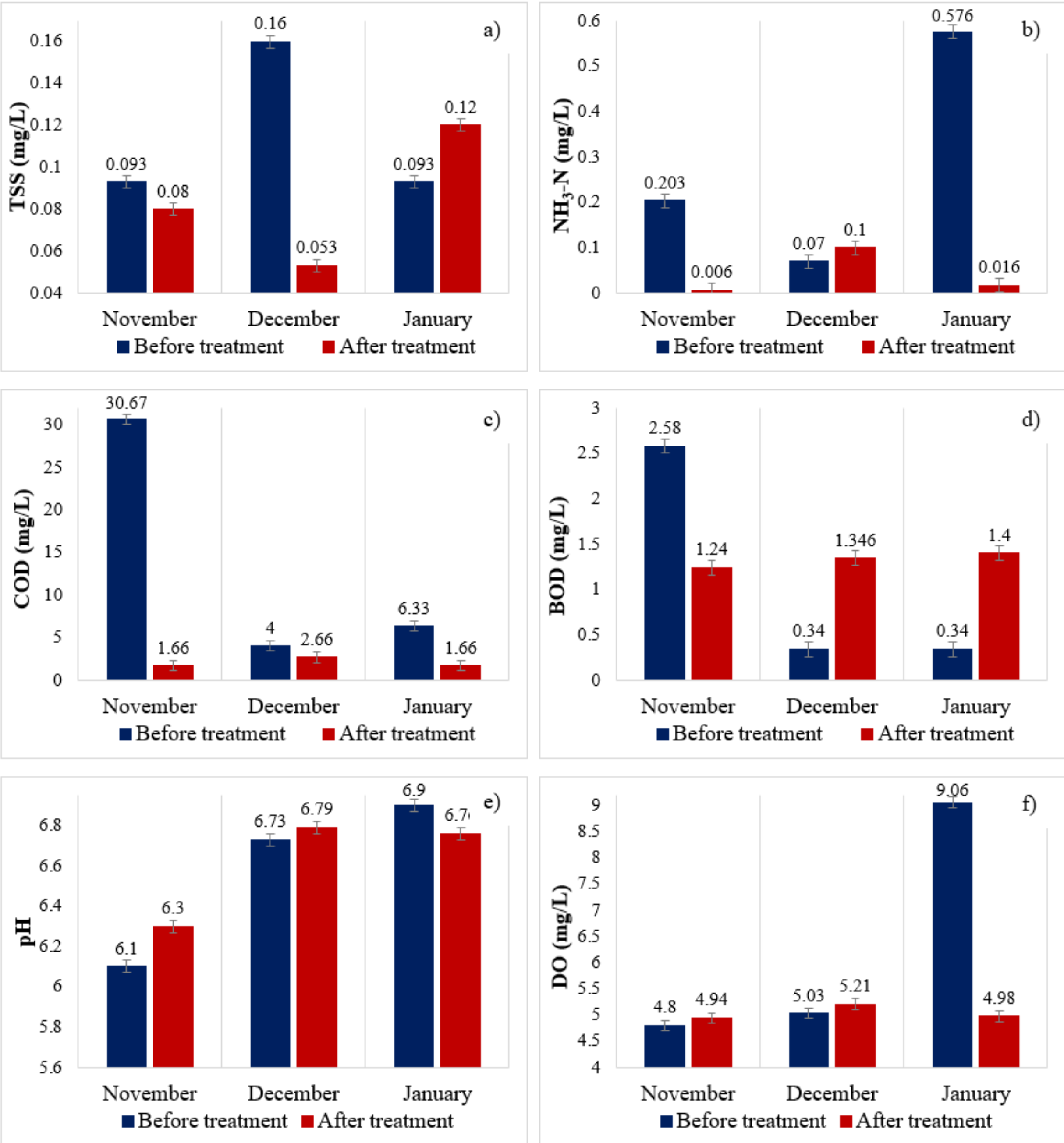

Figure 2. The parameters values of (a) TSS, (b) NH_3N, (c) COD, (d) BOD, (e) pH, and (f) DO, in before and after water treatment.

3.7. Water quality index

Based on the WQI standards in Figure 4, the rainwater quality of before and after the treatments was categorized in class II. The physico-chemical parameters for before and after treatments varies slightly due to the condition of the water that being stored in the tank for a certain duration of times. For class II, the use of water for drinking purposes requires conventional treatments. MyRAWAS is an alternative in overcoming the water supply crisis in KUO. The water collected from the rainwater harvesting system can be used for domestic use such as watering trees, washing cars and utensils and toilet flushing. However, rainwater from this system need to go for further to make it suitable for drinking water and to ensure that the rainwater is completely safe.

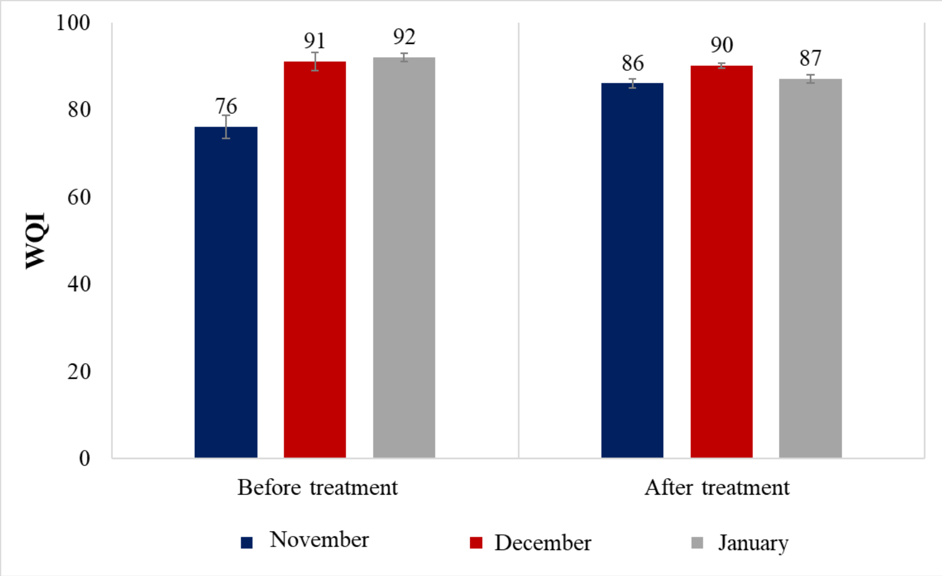

Figure 3. WQI values of before and after treatments

3.8. Biological parameters

Total coliforms were at a safe level according to NWQS (mean values and standard deviations before and after treatment were 38.11 ± 13.96 cfu/ml and 10.33 ± 6.67 cfu/ml, respectively), while the absence of *E. coli* bacteria was recorded for both treatments. This indicates that the roof was exposed to animal faeces. The total presence of these bacteria was in line with the NH_3-N value influenced by the presence of animal faeces. These biological parameters are also important in the determination of water quality. According to NWQS, the total presence of total coliform is in class I, which is at the safe level.

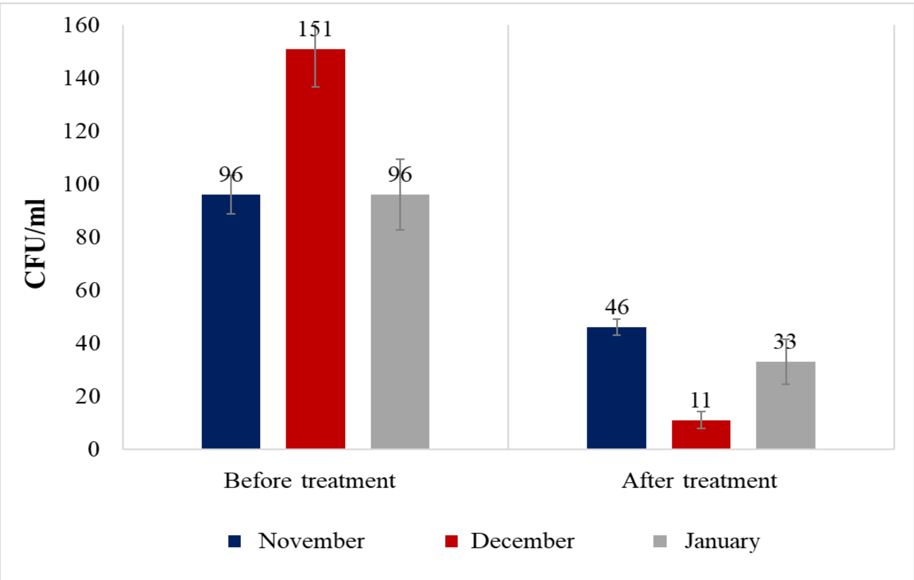

Figure 4. Total coliform values of before and after treatments

4. Conclusions

This study was done to determine the quality of rainwater harvested from roofs of residential college at the College of Ungku Omar, UKM. Rainwater quality before and after treatment were compared to observe the quality of the rainwater samples based on Water Quality Index (WQI). It was found that the quality of water before and after treatment were in class II. Based on the physico-chemical parameters, there are similarities and differences of class for both samplings. For TSS and NH_3-N, both before and after treatment are in class I, while for COD values before treatment and after treatment were in class II and class I, respectively. Other parameters like BOD, pH and DO for before and after treatment were in class II. The usage of water from rainwater harvesting system is suitable for external use and domestic, however, further treatment is needed to be used as drinking water. While for water quality based on biological parameters showed the presence of total coliform bacteria, was higher for water samples before treatment compared to after treatment. There was an absence of *E. coli* bacteria for both water samples. The presence of coliform still at a safe level according to the NWQS.

Rainwater quality studies in these universities should be done regularly and continuously to get the higher quality of harvested rainwater for students' domestic use. This study indirectly helps to increase students' awareness of the importance of rainwater harvesting as an alternative to the existing short water supply. Rainwater harvesting system is very convenient practice primarily in addressing the water crisis. With that, there are several proposals for future research in order to maintain the quality of collected rainwater. Among the recommendations for further research are good maintenance and regular cleaning of the KUO's roof to ensure the cleanliness of the water collected before the rainwater treatment process. Lastly, a more regular monitoring on the rainwater harvesting system is also necessary in order to avoid disruption of rainwater treatment.

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