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CONSUMPTION OF RAINWATER HARVESTING IN TERMS OF WATER QUALITY

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ABSTRACT: Rainwater harvesting is seen as part of solution to avoid water shortage in the future as it offers a sufficient supply and more economical if compare to the conventional way. The scarcity of water supply is becoming a concern due to the growing population of human along with environment pollutions. Rainwater harvesting is considered the most accessible source which could be easily used for potable purposes both for household and commercial activities. Therefore, in this study, the physical, microbiological and chemical rainwater quality samples were analyzed using membrane filtration technique (ELE Paqualab 50), ICP-OES and Hach methods, to ensure the suitability of rainwater harvesting for domestic consumption. The study reveals that overall quality of the rainwater is quite satisfactory as per WHO and Malaysian standards, where the pH, turbidity, total dissolved solids, salinity, NO^{3-}, SO_4^{2-}, Zn and Pb were still under the permissible limits. However, the microbiological parameters (total coliform, fecal coliform and E. coli) and chemical (Cr) were found exceeded the standards, due to poor hygienic practices of the harvesting system. It can be concluded that the rainwater harvesting is still safe to drink and can be a potential alternative source of water supply in the future.

Keywords: Rainwater Harvesting, Water Shortage, Physical Water Quality Parameter, Chemical Water Quality Parameter, Microbiology Water Quality Parameter

1. INTRODUCTION

The 2014 Malaysia water crisis has started in Selangor and Negeri Sembilan from month of February and last for 6 month until August 2014, caused by hot and dry season in Peninsula Malaysia due to El Nino phenomenon. It was the worst crisis in the state since the 1998 Klang Valley water crisis [1]. All 12 water reservoir dams in that area have suffered a substantial drop in water level and led to taps ran dry in more than 10,000 homes affected, and has declared a state of crisis with the water rationing imposed following the water shortage which was the worst has seen in many decades [2]. Primarily, the water shortage is not entirely due to the extreme hot and dry season, but caused of inadequate capacity of Water Treatment Plants and distribution infrastructure towards the imbalance demand and the supply. Malaysia presently relies heavily on surface water treatment plants with approximately 85 to 95% of demand coming from this source. Overreliance on surface water sources is depressing the water level. Every year the water treatment plant water table is dropping down 2 to 4 m due to extreme amount of withdrawal [3],[4]. Excessive exploitation of water supply has been lowering the aquifer level, thus limiting the natural water resources recharge [5]. Moreover, although the existing water supply systems may have been improved, but still the demand is increasing due to the growth of population and the expansion in urbanization, industrialization and agricultural [6]. Nevertheless, environmental issues mainly on pollution and destruction from logging activity, land clearing, natural vegetation changes and pollution of river waters have worsen the scenario [7]. The implementation of rain water harvesting system is one of the alternative methods to avoid water shortage in the future. It could mitigate the water crisis problem, by reducing the burden on current surface water resource, including controlling logging problems and preventing flooding [8]. Malaysia is a most suitable country to practice harvesting rain water and storage, because Malaysia has the most sufficient rainwater supply throughout the years. In Malaysia, the rainfall averaging around 2400 mm for Peninsular Malaysia, 2360 mm for Sabah and 3830 mm for Sarawak [9]. For some rural or remote area they have no water supply from the government, therefore rain water acts as the main water resource. They practice the harvesting rain water from roof runoff that remove only the suspended solid from the rain water and consume directly after boiled.

Although rain water can be one of the alternative sources of drinking water, the viability of rain water quality has become a great concern as it has potential health risk for human consumption. Rain water is one of the abundance water source elements in the world. Natural rain water has the pH of 5.6 that is slightly acidic than neutral because of its equilibrium with atmospheric carbon dioxide [10]. Contaminants in harvested rain water are mainly come from the atmosphere. Originally, before rain falls it is impurities-free but when it does, it begins to collect the atmospheric aerosols that are available surrounding it. When the atmosphere of the area is polluted, the quality of the water will change because as the rain falls, it catches or traps the particulates along the way before reaching to the ground [11]. The atmosphere contains a variety of nutrient ions and metal particulates. Nutrient ions that contain in the atmospheric aerosols such as NO_3^- and SO_4^{2-} which are commonly associated with acidity or alkalinity of the rainwater. These nutrient ions affect the terrestrial ecosystems including agriculture [12]. Meanwhile, when the rainwater contains metal ions such as Cr, Zn and Pb, these affect the soil physic-chemical properties as well as the human health where when consumed will cause harmful effect [13]. The atmosphere also can change the component of the rainwater physically such as its pH, temperature, dissolved oxygen and salinity. It is found from the previous studies [14]-[16] that the first flush of rainwater especially after a long period of dry season has the highest levels of contaminants.

Additionally, the roof material can contaminate the rainwater chemically which makes the rainwater contain heavy metals such as Pb and Zn [17]. Higher Pb and Cu found in rainwater also might be attributed from traffic pollution [18], including lead flashing and roof leaching [19]. The most common contamination for water is microbial contamination. By storing the rainwater, it can be easily be contaminated by bacteria, viruses and protozoa not just from the collector but also from the rooftop that causes sediment buildup [20]. Coliform group of bacteria such as total coliform, fecal coliform and *E. coli* can be easily contained usually after its collection and storing in tanks because of the possible change in water quality during the long periods of storage [21]. According to [22], the microbial contaminants in rainwater harvesting are mainly contributed from improper ways of storing water such as overflow of the tank and unhygienic of the cistern rainwater system. According to [23], the biological pollutant comes from location of the storage tank and surrounding sources such as toilets, under the trees and drains, including uncovered tank from the roof [24]. Therefore, this research is significant in order to provide information on the status and situation of the rainwater quality as per allowable standards in terms of physical, chemical and microbiology quality, thus to determine whether it is suitable and safe to be consumed by human.

2. METHODOLOGY

2.1 Study Area

This research is focusing on untreated drinking water quality from rain water resource at Northern Borneo of Sabah at the East side of Malaysia which is called Tambunan at the latitude of N 05° 31' 53.7" and longitude E 116° 16' 50.4". This location has no treated water supply and only depending directly on rain water to sustain their livelihoods. Majority of houses at the study area are built using the plank materials. This shows that poor communities are living in this low income houses with little access to water supply infrastructure. The physical characteristic at Tambunan area is a hill side with land routes without pavement. This makes the water supply hard to reach to the residential area, and might need high cost from the government to supply water resources to the village. Therefore, rain water acts as the main water resource that plays the important role for these residents to sustain their daily life.

The rain water collection system in this study consisted of three major parts as shown in Figure 1. The first part is the collection of rain water from the roof. Second part is the filter for removing any suspended solids. Third part is the rain water storage into a few thousand liters of container.

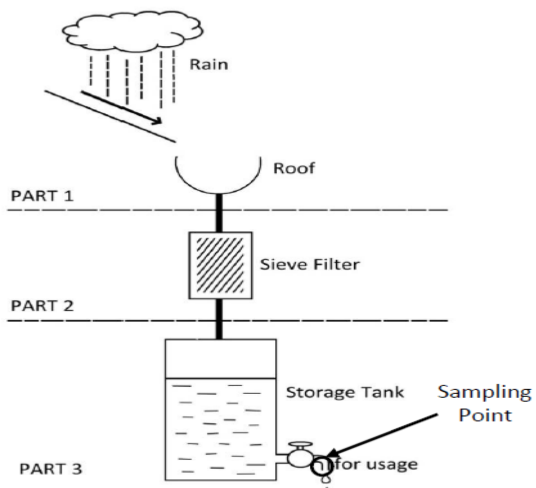

Fig.1 Schematic diagram of the rainwater harvesting system in the study area

2.2 Water Sample Analysis

In this research, water sample analysis covers the physical, chemical and biological parameters. Parameters that were measured which includes the in-situ and ex-situ parameters. The in-situ parameters are conducted for pH, salinity, turbidity, and total dissolved solids, and are measured using the equipment shown in Table 1.

Table 1 Types of equipment for different *in-situ* parameters

Parameter	Unit	Device	Brand/Model/Series No.
pH	-	pH meter (portable)	Mettler Toledo/ Seven Go/ 1231355617
Salinity	ppt	Salinometer	YSI EC300/ JC 01595
Turbidity	NTU	Turbidimeter	TN-100
Total Dissolved Solid	mg/L	Electrical conductivity meter	YSI EC300/ JC 01595

There are total of 120 household owners involved during the rainwater samples collection. The samples were taken either from ground/surface tanks or above-ground tanks, and in some cases are constructed as part of the building, and some built as a separate unit located distance from their house. However, most of these tanks receive rainwater from roof tops with 5 m^3 to more than 50 m^3. Water can be easily extracted through a tap above the tank base or by water pump channeled into the house water pipe.

The ex-situ parameters that were analyzed including the total coliforms, fecal coliforms, E. coli for microbiological parameter; nitrate, sulphate for nutrients and Cr, Zn and Pb for heavy metals analysis. The total coliforms, fecal coliforms and E. coli test are conducted using membrane filtration technique (ELE Paqualab 50) by [25] Standard. The total coliforms, fecal coliforms, and E. coli were measured by using colony forming units per 100 mL (CFU/100 mL) of water. For this technique, a nutrient solution which is MLS is used to culture the growth of bacteria. All the apparatus were washed thoroughly with diluted nitric acid and distilled water. Autoclave of apparatus was also carried out at 121°C for 1 hour and 30 minutes in order to ensure complete sterilization. Filter unit was rinsed thoroughly of distilled water before the process of filtration. Water sample of 100 mL of volume was measured and poured through a 47mm membrane filter. While the water is flowing through the filter, the petri dish was prepared by placing an absorbent pad. After that, 10 mL of Membrane Lauryl Sulphate (MLS) broth solution was added onto the absorbent pad. After the water sample has completely flow through the membrane filter, it was then be removed by using forceps and placed on the cover of the absorbent pad containing MLS in the petri dish. After that, the petri dish was sealed firmly by using parafilm and placed into an incubator and incubated at 37°C ± 5°C for 24 hours for total coliform and 44°C for E. coli respectively. After 24 hours, the petri dish was removed from the incubator. The colony was ready to be counted under a 10-15X magnifier. Eventually, the formation of colonies were counted and recorded. The total coliform, fecal coliform and E. coli were then counted by using the formula of colony forming unit (CFU) per 100 mL:-

$$= \frac{\text{Colonies counted}}{\text{mL or original sample filtered}} \text{ x } 100$$

For heavy metals analysis, rain water samples were preserved by using concentrated nitric acid (HNO_3) below pH 2. Next, 100 mL of sample was taken using measuring cylinder. Then, filter the water sample with 45 µm of membrane filter and transfer into the 250 mL of beaker. Next, a series of calibration standards for each heavy metal was prepared by pipetting aliquots of standard solution into a series of volumetric flasks. After that, the rain water samples together with the standard solutions and blank solutions were measured by using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPOES) machine and the absorbance value for the standard and samples were recorded. The metal concentrations for each sample were determined using the absorbance value by the standard calibration graph.

For nitrate (NO^{3-}) and sulphate (SO_4^{2-}) analysis, the preparation of sample was prepared in a first square cell that will involves 10 mL of water sample add with the Nitra Ver 5 Reagent Powder Pillow. The blank preparation was prepared in a second square cell of 10 mL distilled water. Nutrient analysis was carried out using Hach Kit, and result was then shown on the screen display of the Hach Kit. As for sulphate, similar analysis was done by preparing sample and blank. The preparation of sample was prepared in a first square cell that involves 10 mL of water sample add with the Sulfa Ver 4 Reagent Powder Pillow, and the blank preparation was prepared in a second square cell of 10 mL distilled water. Sulphate analysis was then carried out using Hach Kit. In this study, all the data were statistically analyzed using the SPSS version 21.0. ANOVA analysis determine the differences and to see the effect of locations on physical, microbiological and chemical parameters of the rainwater samples at $p<0.05$ significance level. Thus identify the sources of contaminations in harvested rainwater.

3. RESULTS AND DISCUSSION

3.1 *In-Situ* Parameters Analysis

In this study, the in-situ parameters analysis which includes pH, turbidity, total dissolved solid and salinity were performed. These in-situ analyses were carried out by using electrometric method. All the measured values are then compared to the National Standard for Drinking Water Quality (NSDWQ), World Health Organization 2011 (WHO 2011) and Malaysia Drinking Water Quality Standard (MDWQS) as shown in Table 2.

Table 2 Measurement results of the investigated *in-situ* parameters from rainwater samples

Parameter	Units	Min	Max	Average	Max Level NSDWQ Standard	Max Level WHO Standard	Max Level MDWQS
pH	-	6.56±0.21	7.13±0.30	6.83±0.27	6.5 – 9.0	6.5 – 8.5	5.5 – 9.0
Turbidity	NTU	0.48±0.02	1.27±0.04	0.89±0.32	0 - 5	0 - 5	0-5
Total Dissolved Oxygen (TDS)	mg/l	4.23±0.06	36.40±0.10	12.94±10.16	1500	1500	1500
Salinity	ppt	0.00×10^{-9} ±0.0	0.00×10^{-9} ±0.0	0.00×10^{-9} ±0.0	-	-	-

Overall, the pH value for all house tanks comply 100% with all the drinking water quality standards. Statistical analysis shows that there is significant differences of pH value ($p=0.004$; $p<0.05$) in all sampling stations. The pH value in the rain water can be varies due to the atmospheric clean-up process by the rain [26]. Normal rain has the pH of 5.6 but the pH can be naturally altered after the rain has washed-up the atmosphere and collected by the roof. According to [27] the atmospheric chemicals that are naturally emitted from the earth crush aerosol is the major contributor to the pH changes. However, the pH for all the rain water samples in the study area is all above 5.6. According to [28], human activities such as limestone quarry and industrial activities can also contribute the rainwater become alkaline. The study area is far from limestone quarry and industrial activities, and located at the remote location with least amount of vehicles, thus transportation is not a major factor to effects the pH in rain water harvesting quality in this area. The turbidity and TDS are also fall within the safe drinking water quality standards with 100% compliance and $p=0.000$ significance difference in tanks location. Low levels of turbidity and TDS concentrations show the rainwater is clear. For salinity level, the rainwater has recorded 0.00×10^{9} salinity concentrations in all sampling stations, which shows a very little and no salinity content in the rainwater.

3.2 *Ex-Situ* Parameters Analysis

In microbiological analysis, the colony forming unit (CFU) for total coliform, fecal coliform and *E.coli* are determined in the rainwater samples. The results in Table 3 shows that all collected rainwater samples are heavily contaminated with microbes under the allowable standards of WHO and NSDWQ.

Table 3: Measurements for microbiological parameters (coliform group)

Parameter	Units	Min	Max	Average	Max Level NSDWQ Standard	Max Level WHO Standard	Max Level MDWQS
Microbiological Parameter (Coliform Group)							
Total Coliform (TC)	CFU/ 100mL	11±14.8	143±9.9	62±43.4	0	0	5000
Fecal Coliform (FC)	CFU/ 100mL	10±14.1	132±8.5	54±41.8	0	0	0
E-coli	CFU/ 100mL	0.5±0.7	58±2.8	32±25.8	0	0	0

According to [29], the microbiological quality of the harvested tank is influenced by roof catchment and runoff contamination. The feces of birds, insects and small mammals, including atmospheric deposition of environmental organisms are then run off into the tank which will increase the fecal coliform. Consequently, the high contaminated of the coliform can be due to the poor hygiene practices of the harvesting system [8]. Cleanliness of the roof, filter and tank should be in good hygiene practiced. According to [30], high contaminated of coliform can be due to holes exist on the filtered, insects and mesh formed, dirty drainage near to the tank and moisture condition.

These are almost the same reasons can happened in the study area.

Statistical analysis shows that all the coliform groups are significant between every stations, where $p<0.05$. Although TC are presence in all the water samples, but under Malaysia Drinking Water Quality Standard (MDWQS) for raw water, the maximum permissible limit for total coliform can reached up to 5,000 CFU/100 mL of water. Therefore, the rainwater samples in this research are still complied with MDWQS standard. From field observations, the rainwater sample after boiled reduces the microbial growth or totally killed until 0 CFU microbes.

In chemical analysis, heavy metals which include chromium (Cr), zinc (Zn) and lead (Pb), and nutrients such as nitrate (NO^{2-}) and sulphate (SO_4^{2-}) have been determined. From Table 4 the readings of Cr concentrations in harvested rainwater found exceeded all the standards.

Table 4: Measurements for heavy metals

Parameter	Units	Min	Max	Average	Max Level NSDWQ Standard	Max Level WHO Standard	Max Level MDWQS
Heavy Metals							
Chromium	mg/L	0.30± 0.00	0.41± 0.01	0.35± 0.09	0.05	0.05	0.05
Zinc	mg/L	0.29± 0.00	2.37± 0.02	1.24± 0.79	3	-	3
Lead	mg/L	0.0×10^{-3} $\pm0.0\times10^{-3}$	6.5×10^{-3} $\pm3.9\times10^{-3}$	3.3×10^{-3} $\pm3.8\times10^{-3}$	0.01	0.01	0.01

According to [31], the high contamination of chromium is often found in rain water, where rain is passing through the roof cause from leaching and atmospheric fly ashes [32]. The cleanliness of the roof plays the important role in Cr concentration in the harvested rain water. To overcome this problem, one of the best suggestions is to clean the roof catchment at least once in every month. From this research, it is found that all the homeowners did not clean the roof catchment more than a year. This explains why high level of Cr leaching from the roof runoff [33]. For Zn, overall analysis shows that all the concentrations of Zn in harvested rainwater samples are satisfactory. All samples fulfilled the standards.

According to [34], high concentrations of Zn found in harvested rain water sample are usually from the coal burning, fossil fuels and smelting of non-ferrous metals. Study area shows a lower Zn concentration as there is none of this activity exists in this area. Thereby, the Zn concentrations in the entire rainwater tanks are not exceeded the allowable limits. For lead (Pb), all samples are also detected to fulfill all the standards which are below 0.05 mg/L as shown in Table 3. In [35] did mention that Pb is one of the non-crust-dominated trace metals and its concentration can vary during an individual rain event. Based on this reason, it explained why Pb exists in the rain water sample. According to [36], Pb emission can be also from the industrial activities and motor vehicles which can transport through a long distance in the atmosphere. Fortunately, Tambunan is located far away from main town. As a result, rainwater samples in Tambunan do not contains high levels of Pb.

For nutrients, nitrate (NO^{3-}) and sulphate (SO_4^{2}) levels in all stations also were recorded lower and not exceeded all the permissible standards as shown in Table 5.

Table 5: Measurements for nutrients

Parameter	Units	Min	Max	Average	Max Level NSDWQ Standard	Max Level WHO Standard	Max Level MDWQS
Nutrients							
Nitrate	mg/L	1.17± 0.06	5.57± 0.93	2.33±1.52	10	10	10
Sulphate	mg/L	0.33± 0.58	1.67± 0.58	0.91±0.46	250	250	250

According to [37], NO^{3-} is naturally occurring from the nitrogen contained in soil and water, where associated by Ca^{2+}, Mg^{2+}, K^+ and Na^+. In this research, the small amount of NO^{3-} is still exist in the harvested rain due to the natural process of broken down of organic matters by bacteria where cannot fully uptake by plants [38]. Next, these remaining organic matters are dissolved by the rain water and bring into the harvesting system. According to [39], the natural process such as oxidation of elemental sulphur, sulphide minerals or organic sulphur will increase the SO_4^{2-} levels in the harvested rain. This explained why there is still SO_4^{2-} contains in the harvested tank water sample although it is free from industrial activities. All this reaction contributes to the emission of sulphuric acid to the rain.

4. CONCLUSION

The results of microbiological colonies forming unit examined across Bogian Village shows the sequence, where total coliform > fecal coliform >E. coli. For chemicals analysis, the sequence concentrations of heavy metals found in the harvested rainwater were Zn > Cr > Pb and the sequence for nutrients concentrations shows NO^{3-} $>SO_4^{2-}$. The research also showed there are variations of microbes, nutrients and heavy metals in the rainwater quality according to locations. In statistical analysis, all the coliform bacteria (total coliform, fecal coliform and E. coli), Zn and NO^{3-} in rainwater samples shows significant difference ($P<0.05$) between every houses. In contrary, the concentration for Cr, As, Pb and SO_4^{2-} did not show significant differences ($P>0.05$). The water quality parameters for Zn, Pb, NO^{3-}, SO_4^{2-} were found to complied the National Standard for Drinking Water Quality (NSDWQ), World Health Organization Standard 2011 (WHO 2011) and Malaysia Drinking Water Quality Standard (MDWQS). However, in contrast, the collected rainwater samples in the research mostly were detected to be heavily contaminated with microbes and Zn metal, which was recorded, exceeded the allowable limits. This due to the poor cleanliness and less hygiene practiced of the harvesting system. Therefore, several environmental conditions should be taken into consideration in this harvesting system in order to improve the water quality such as a proper design and operation, regular monitoring, periodical maintenance of the collection systems, cleanliness of the catchment area and location of the collection tanks away from any septic leakages. Finally, the overall quality of rainwater was found quite satisfactory and implies that the system could be sustained during the critical periods of water supply, as well as during normal periods. Rainwater harvesting is seen as an effective option not only to recharge the surface water aquifer but also to provide adequate storage of water for future use. The system could become a good alternative source of water supply to cope with the ever increasing demand and should be utilize as a community facility.

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