Sustainable Clean Water Production Using Bamboo Activated Carbon for Rural Residents in the Borneo Island

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In Sarawak, a state of Malaysia on Borneo Island, clean water supply coverage is estimated to be 81.4% in 2020, whereby those without access to clean water are rural residents. Although the state aims to achieve full clean water supply coverage by 2025, budget limitations make this impossible. This research proposes a decentralized water supply system that harvests rainwater and river water to supply rural households with clean water. The selected study area is Pelaman Monggak, a rural village in Bau District, Sarawak. The rainwater storage tank was modelled using the Tangki NAHRIM (NAHRIM Tank). The results showed that for a rural household of five people, the reliability for a tank size of 2 m^3 is 84.5%. From 2010 to 2019, the rainwater storage tank can supply rainwater for 3044 days, with the remaining 608 days supplied by river water. As river water is not safe for potable use, treatment is needed. The proposed water treatment process for river water includes bamboo activated carbon adsorption, membrane microfiltration, and UV disinfection to improve the river water quality from Class II to Class I. For rainwater, two treatment processes, namely membrane microfiltration and UV disinfection, are sufficient to produce safe drinking water quality.

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INTRODUCTION

According to the Malaysia Ministry of Utilities (2020), Sarawak's current water supply coverage stands at approximately 81.4% of the population. According to Sarawak Government (2020), the state's population is 2471140 people. An estimated 459,633 people do not have access to clean water, and all of them are rural residents, as residents living in major cities throughout the state are well supplied with clean water.

According to Goh (2019), many rural communities in Sarawak are facing shortages of clean water, and this problem is further exaggerated during the drought season. It is especially prevalent in rural and remote places in Ulu Baram, Lawas, and rural Miri. There are no central water supply pipelines in these rural areas, as it is impractical to construct water treatment plants and water supply pipelines in remote areas with small populations. According to Pentadbiran Bahagian Sibu (in English, it is called as Sibu Division Administration) (2020), in the present day, these rural residents who have no clean water supply are mainly using raw collected rainwater and river water for their daily uses. This practice poses a risk, as untreated river water contains high levels of pollutants. Moreover, the current method of collecting rainwater is inefficient. Rural residents do not have a properly designed system to harvest and store rainwater to prevent contamination, which is harmful and may lead to waterborne diseases.

In Sarawak, the main suppliers of water are the Kuching Water Board (KWB), Sibu Water Board (SWB), Northern Region Water Board (NRWB), and the Sarawak Rural Water Supply Department (in Malay, it is called as Jabatan Bekalan Air Luar Bandar) (JBALB) (Kuok and Chiu 2018). The function of JBALB is to supply the rural residents with water, and their goal is to ensure 100% coverage for all rural residents by the year 2025. According to the Ministry of Utilities (2020), the initiative to realise this goal was named Sarawak Alternative Water Supply (SAWAS). SAWAS is focused on building centralised water treatment plants in rural areas while utilising processes such as ultrafiltration and reverse osmosis. The method SAWAS is adopting may be suitable for larger rural communities. While the SAWAS initiative is an excellent initiative to address the need for a hygienic water supply in some rural areas, specific problems may eventually arise.

While there are government efforts to build centralised water treatment plants for some rural communities as part of the SAWAS initiative, substantial funding will be required to extend this initiative throughout the state, considering the current clean water supply coverage only stands at 81.4% (Kuok *et al.* 2020). Although the federal government allocates funding to the SAWAS, it is not enough to achieve the goal of 100% clean water supply coverage throughout the state by 2025. The cost of setting up a water treatment system can be substantially high, as it includes the cost of constructing the entire water treatment facilities and connecting to a water distribution network.

Hence, JBLAB needs to take a different approach under the SAWAS initiative. It is possible to rely on current abundant water sources such as rainwater while adopting a decentralised supply for each rural household instead of for an entire rural community. This solution can help overcome existing challenges being faced by the SAWAS initiative to ensure that 100% clean water supply coverage is achieved. This goal will improve the rural residents' quality of life. However, the optimum rain harvesting tank size for the rural community in tropical regions is unknown, and developing a decentralised water treatment system for rural households at the lowest cost is uncertain. Therefore, this research is conducted to design an integrated water supply system through rainwater harvesting and river water treatment for rural communities in Sarawak.

Study Area

The selected rural study area is Pelaman Monggak, located at the latitude of 1°19'60.0"N (1.3333300°) and longitude of 110°07'00.0"E (110.1166700°). Pelaman Monggak is situated southwest of Kerokong Gunong Village (Kampung Kerokong Gunong), and northeast of Pedaun Bawah Village (Kampong Pedauun Bawah). Pelaman

Monggak is a gold mining town in the Bau District, Kuching Division of Sarawak, Malaysia. Monggak River (Sungai Monggak) is a stream adjacent to Pelaman Monggak with 57 metres. Besides Monggak River, two nearby streams are named Sibuh River (Sungai Sibuh) and Terobong River (Sungai Terobong) (Ling *et al.* 2017). Currently, Pelaman Monggak was developed into one of the best hiking trails in Sarawak. The two famous hiking trails available within Pelaman Monggak are Libiki Bamboo Resort Jungle Trail and Pedaun Bawah National School (Sekolah Kebangsaan Pedaun Bawah), with a total distance of 1.41 miles and 0.91 miles, respectively. The layout of Pelaman Monggak is presented in Fig. 1.

Fig. 1. The Monggak River (Sungai Monggak), Plaman Monggak, Pedaun Bawah Village (Kampung Pedaun Bawah), Kaman Village (Kampung Kaman), and Blimbin Village (Kampung Blimbin) (Kuok *et al.* 2011)

Table 1. Annual Rainfall Date from Monggak (Lai and Kuok 2019)

Annual Rainfall	
Year	**Total (mm)**
2000	4284
2001	4028.5
2001	5040
2003	5671.5
2004	4282.5
2005	3948.5
2006	4376.5
2007	3798.5
2008	3942
2009	4510
Average annual rainfall	4388.2

The rainfall data were collected from DID rainfall Monggak across 10 years, from 2010 to 2019. Within the 10 years, there were 1465 days where no rainfall was recorded. The rainfall daily frequency recorded in Monggak was 59.88%. The yearly rainfall data are summarized in Table 1. The table 1 shows the highest annual rainfall recorded in 2003 with 5671.5 mm. In contrast, the annual rainfall of 3798.5 mm in 2007 was the lowest annual rainfall. Overall, the average annual rainfall across the 10 years was computed as 4388.2 mm, and the average monthly rainfall is presented in Table 2.

Table 2. Annual Rainfall Date from Monggak (Lai and Kuok 2019)

Annual Monthly Rainfall	
Month	**Total (mm)**
January	821.9
February	478.1
March	376.4
April	329.5
May	255.3
June	175.6
July	235.6
August	225.3
September	321.3
October	331.4
November	388.7
December	503.5

Referring to Table 2, the months with the highest average rainfall are in January, followed by December. The months that experienced the least rainfall were in the middle of the year, from April to August, and the lowest average rainfall happened in June. These results are consistent with findings from Ahmad *et al.* (2017) and Sivanandam *et al.* (2019), which stated that Malaysia experiences the dry season from May to September due to the southwest monsoon, resulting in lower rainfall and the wet season from November to March due to the northeast monsoon.

EXPERIMENTAL

The methodology for this research was split into two parts, as shown in Fig. 2. The first part involved the determination of rainwater storage tank size through software analysis using NAHRIM Tank (Tangki NAHRIM), a software developed by the National Hydraulic Research Institute of Malaysia (NAHRIM). The second part of the methodology involves designing the rainwater and river water treatment process incorporating bamboo activated carbon adsorption, membrane microfiltration, and UV disinfection. The final treated water quality parameters can meet the requirement of Class I requirements of the National Water Quality Standards (NWQS) for Malaysia.

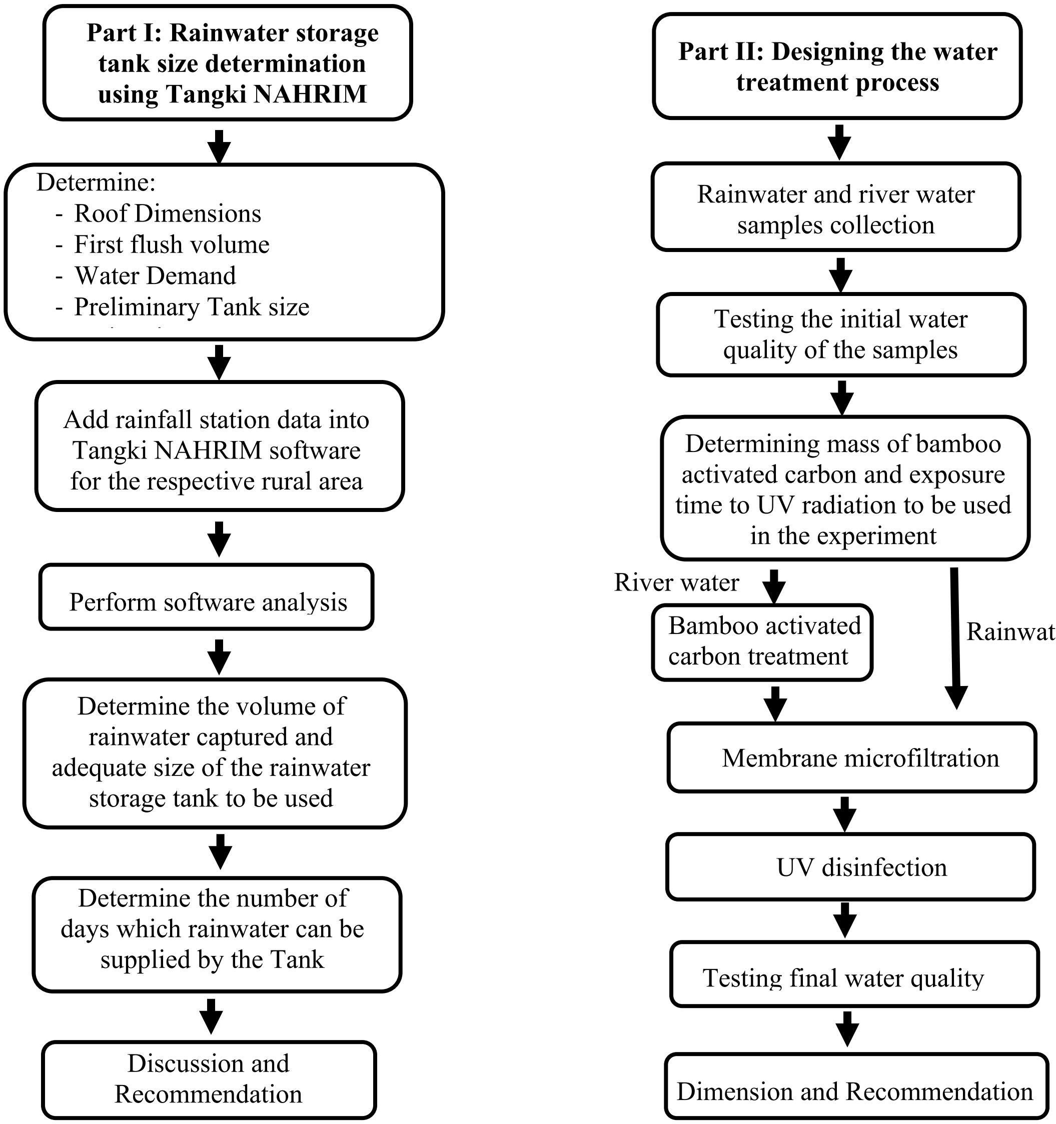


Fig. 2. Flow chart for research methodology

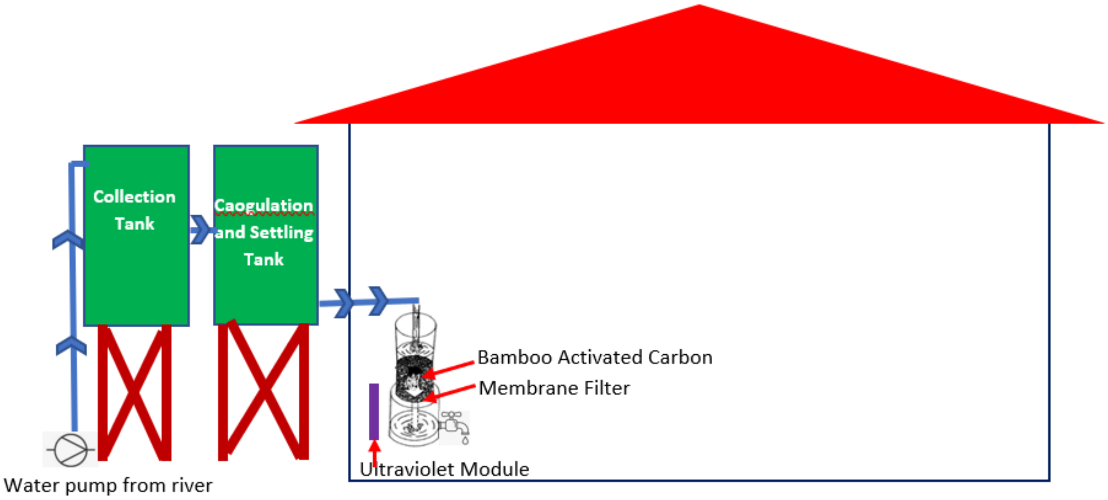
Part I: Determine Rainwater Storage Tank Size using NAHRIM Tank (Tangki NAHRIM)

For analysis, the rainfall data for the rural area, Pelaman Monggak, was collected from 2010 to 2019. The roof size, first flushes volume, and water demand is determined according to the guidelines from Urban Stormwater Management Manual for Malaysia, MSMA 2nd Edition (DID 2011). As the roof size area for rural houses is below 100 m^2, the first flush volume was taken as the recommended 0.05 m^3 (Lani *et al.* 2018) for flushing the contaminants at the roof. The first flush technology functions to prevent a specific volume of firstly harvested rainwater from the roof from entering the rainwater storage tank (McIntyre *et al.* 2019). The relevant runoff coefficient for the metal roof adopted in this study is 0.9 (Kuok and Chiu 2020). The domestic daily water demand required for rural household are listed in Table 3.

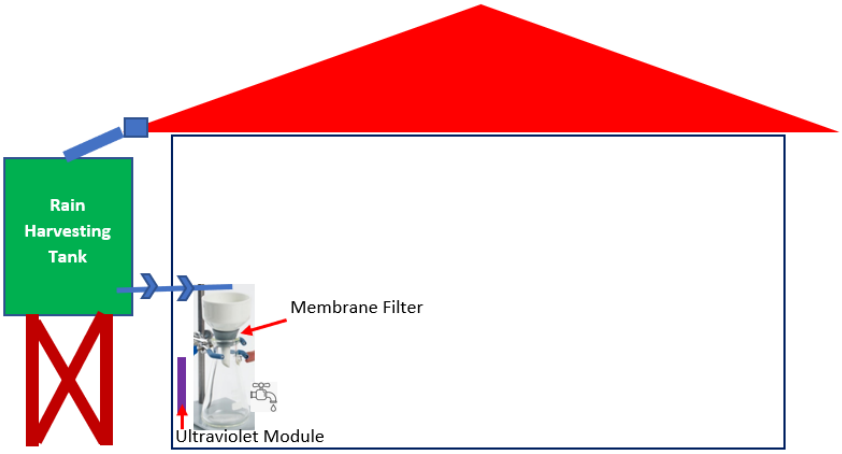
Table 3. Daily Water Demand per Person

Activities	**Water Demand (L)**
Drinking	4
Cooking	6
Personal hygiene	50
laundry	20
Utensils Washing	10
House Cleaning	15
Toilet	35
Total	**140L/person/day**

It was assumed that there are five members in a family. Once all the water demand parameters were identified, the rainfall data obtained from DID Sarawak was input into Tangki NAHRIM for determining storage tank size. Rain harvesting tanks with the sizes of 1.5 m^3, 2.0 m^3, and 2.5 m^3 were investigated to check the reliability ratio, percentage of time tank empty, and the number of days when rainwater is supplied to rural households.



a) River Water source



b) Rainwater source

Fig. 3. Schematic diagram of the envisioned treatment system for a household utilising river and rainwater sources

A rainwater storage tank should be adequately sized to cater to the household's water demand. If the rainwater is found insufficient, then the water supply for the rural household is backed up with treated river water. The schematic diagram of the envisioned treatment system for a household using river water and rainwater is presented in Figs. 3a and 3b, respectively.

The harvested rainwater may accumulate contaminants, making it not safe enough for portable use. Therefore, the harvested rainwater must undergo treatment to achieve Class I water quality under NWQS (Texas Water Development Board 2005). Developing the domestic water treatment system involves adsorption, filtration, and disinfection.

Part II: Design of Rainwater and River Water Treatment System

The design of household-scale river water systems incorporates coagulation and settling processes using aluminum sulfate, adsorption treatment processes using bamboo activated carbon, filtration using a microfiltration membrane, and disinfection using ultraviolet (UV) radiation. Meanwhile, two treatment processes are incorporated for treating rainwater namely filtration and disinfection. Rainwater and river water samples were first collected. The raw water quality was tested, and the samples were treated. The final water quality was compared with the initial water quality to determine the performance of the water treatment system. The river water samples are collected from Monggak River (Sungai Monggak), and the rainwater samples are collected from a metal roof.

In this experiment, the tested parameters were total suspended solids (TSS), dissolved oxygen (DO), ammonia (NH_3-N), pH, and turbidity. The TSS, turbidity, and NH_3-N tests were conducted using a Hach kit (HACH, Loveland, CO, USA). A DO test was conducted using a portable dissolved oxygen (DO) meter (YSI, Yellow Springs, OH, USA), while a pH test was relatively simple and was conducted using a pH meter. All the parameters except turbidity are parameters adopted by the Department of Environment (DOE) to determine the WQI of the water. These parameters were compared with the guidelines set by the NWQS of Malaysia.

The pretreatment method for river water is mixing with aluminum sulfate through coagulation and setting processes with appropriate coagulant dosage and pH to remove turbidity. The passage time for coagulation and settling processes is about 1 to 1.5 hours. The next treatment process is adsorption process using activated carbon. In this study, bamboo activated carbon was used due to its higher carbon content than conventional coconut shells, and it is also widely available in Sarawak (Pham *et al.* 2013). Bamboo activated carbon is extremely effective at removing unpleasant tastes, odors, color, chlorine, volatile organic compounds, pesticides, and a group of suspected carcinogens (Amosa *et al.* 2016). Removal occurs through adsorption processes based on surface interactions between pollutants and carbon graphitic platelet surfaces. In a nutshell, activated carbon works like a sponge, absorbing contaminants in the water through a vast surface area. One pound of activated carbon has a surface area of 125 acres or 50.6 hectares. Compared to carbons with larger particle sizes, powdered micron-sized activated carbon particles demonstrate faster kinetics and a greater capacity for contaminant removal.

Van der Waals forces, including induced dipole interactions, are responsible for these contaminant-carbon surface interactions. Neutral organic molecules are converted into intramolecular dipoles by activated carbon graphitic platelets. The generated dipoles bind and cling together to the molecules, causing them to precipitate out of the solution in the carbon's nano-sized pores or adsorption spaces. This is also known as premature condensation, facilitated by activated carbon.

Pretreatment before membrane filtration is vital as it helps to reduce membrane fouling or accumulation of particles on the membrane. It improves the membrane filter's lifespan (Li *et al.* 2020). Through the bamboo activated carbon adsorption, water quality improves before membrane filtration, thus enabling higher efficiency in removing contaminants.

For the bamboo activated carbon adsorption process, 900 mL of river water was stirred with 0.72 g of bamboo activated carbon for 10 minutes. The bamboo activated carbon is removed, and 300 mL of the water was poured into an incubation bottle for testing the water quality parameters. After five days, the water sample was tested for the final DO level to obtain the BOD_5.

The second treatment method for river water and first treatment process for rainwater is performed using membrane filters. The function of membrane filtration is to retain the larger particles than the membrane pore size include coagulant and bamboo activated carbon, except for tiny bacteria and viruses (Helmreich and Horn 2009). The two common types of membranes used are microfiltration and ultrafiltration membranes, where ultrafiltration membranes have a smaller pore size. However, ultrafiltration membranes are slightly better at improving water quality parameters than microfiltration membranes, which already have high efficiency in improving water quality parameters (Szymański *et al.* 2019). Also, the use of microfiltration membranes is more justifiable than ultrafiltration membranes from an economic standpoint (Szymański *et al.* 2019). Hence, this research adopts the use of microfiltration membranes.

The vacuum filtration set apparatus was set up as shown in Fig. 4. The microfilter membrane of 0.45 µm pore size was placed at the bottom of the Buchner funnel. The vacuum pump was switched on to create a vacuum in the Buchner flask. A total of 600 mL of the river water treated with bamboo activated carbon process was passed through the 0.45 µm membrane. After membrane filtration, 300 mL of the water sample was poured into an incubation bottle for testing the water quality parameters. The membrane filtration process takes about 5 to 10 minutes with the help of vacuum set apparatus. The water sample was stored at 4 °C for five days for determining BOD_5.

Fig. 4. Vacuum filtration set apparatus

The final process for both river water treatment and for rainwater is disinfection. Disinfection can be performed using an ultraviolet (UV) lamp, and it is important to inactivate the harmful bacteria and viruses that have passed through the membrane during the filtration process (Melidis *et al.* 2009). It is crucial to expose the water to UV radiation for an extended period, as the effectiveness of UV radiation at inactivating the bacteria and viruses in water increases with time (Kollu and Örmeci 2015). However, if the water flow rate is too high, a UV lamp of a higher power rating can be adopted to ensure adequate exposure.

Water samples of 300 mL were exposed to a 6W UV lamp for 10 minutes. The disinfection process was set up in a dark and controlled environment without any external light sources using a cardboard box. After 10 minutes, the 300 mL water sample was poured into an incubation bottle for testing the final water quality parameters. The results from seven rainwater and river water samples were compared. Similarly, the water sample was kept for five days to determine the BOD_5.

RESULTS AND DISCUSSION

Part I: Rainwater Storage Tank Size using Tangki NAHRIM

A total of three different sized storage tanks, including 1.5, 2.0, and 2.5 m^3, were analysed using Tangki NAHRIM, and the results are presented in Table 4. The reliability ratio, which was calculated based on the volume of water supplied over the volume of water demand, was preferred to be within the range of 80% to 90% to maximise the efficiency of the rainwater storage tank. A rainwater tank with a less than 80% reliability ratio is deemed inadequate. However, a tank with a reliability ratio of above 90% is commonly too high-priced and, therefore, not a viable economic option. Referring to Table 4, the reliability of the 1.5 m^3 tank size was only 79.67%. Using a 1.5 m^3 storage tank found that water supply is insufficient to meet the water demand for 807 days, equal to 22.1% over ten years. Hence, a rainwater tank size of 1.5 m^3 is not suitable.

Table 4. Analysis of Tangki NAHRIM for Different Sizes of Rain Harvesting Tanks

Volume (m^3)	1.5	2.0	2.5
Reliability Ratio (%)	79.67	84.50	87.46
Reliability per Volume (%/m^3)	53.11	42.25	34.98
Total Volume of Supplied Rainwater (m^3)	1482.98	1573.02	1628.14
Number of Days Rainwater is Supplied	2845	3044	3167
Number of Days Rainwater is Not Supplied	807	608	485
Average Number of Days in Year Rainwater is Not Supplied	81	61	49
Percentage of Time Tank is Empty (%)	22.10	16.85	13.28

The reliability ratio per volume was obtained by dividing the reliability ratio by the rainwater tank volume. Table 4 reveals that as the volume of the rainwater tank increased, the reliability per volume decreased. When rainwater tank size increased from 1.5 m^3 to 2.0 m^3, the reliability ratio was increased from 79.67% to 84.50%. In contrast, as the tank volume increased from 2.0 m^3 to 2.5 m^3, there was only a minor improvement in the reliability ratio. Hence, based on the data, it was more feasible to adopt the 2.0 m^3 rainwater tank over the 2.5 m^3 rainwater tank, as the reliability per volume was computed to be

42.25%/m^3 for a 2.0 m^3 tank size reduced to 34.98%/m^3 for 2.5 m^3. This result indicates that investment in the 2.0 m^3 tank is more economical yet achieves a higher reliability ratio per volume.

Table 4 also shows that the 2.5 m^3 rainwater tank could supply water for 3167 days over ten years, while the 2.0 m^3 rainwater tank can only supply water for 3044 days. However, the improvement was only marginal, and it was not as feasible due to higher cost allocations for achieving marginal improvements. On average, it was estimated that the 2.5 m^3 rainwater tank could not supply water for 49 days yearly, compared with 61 days for 2.0 m^3. However, the improvement is not significant.

The increment for the reliability ratio was also very minimal, from 84.50% to 87.46%, which was only roughly a 3% increase. However, both the 2.0 m^3 and 2.5 m^3 tanks reached the 80% reliability ratio threshold. Hence, the best size of the rainwater harvesting tank was 2.0 m^3. The 2.0 m^3 rain harvesting tank is unable to supply water for 61 days per year, which is substituted by river water during this period by collecting the water from river manually.

Part II: Rainwater and River Water Treatment System

River water system

Table 5 shows the results obtained from the treatment of river water samples using bamboo activated carbon, microfiltration over a 0.45 μm membrane, and UV radiation. Raw river water samples collected from the Monggak River (Sungai Monggak) indicate that the river is of Class II (Department of Environment 2019). After the bamboo activated carbon adsorption process, most water quality parameters were improved for TSS, turbidity, and NH_3-N parameters. In samples where the adsorption process did not adequately remove these parameters, the water quality was improved to achieve Class I water quality through the membrane microfiltration process. The function of the UV disinfection to kill viruses and bacteria for potable usage. The pH level remained consistent and was always within Class I before and after all treatment processes. However, the DO concentration decreased during bamboo activated carbon adsorption. This was attributed to the oxygen being absorbed by the bamboo activated carbon, as it accepts electrons found on the activated carbon (Liu *et al.* 2012). The percentage of containments removal was calculated using Eq. 1.

Percentage removal efficiency = (influence parameter – effluent parameter)/influent parameter x 100% (1)

The removal percentage of TSS from bamboo activated carbon adsorption was between 67% and 100%. The removal percentage in samples 3 and 5 was less than 80%, whereas the remaining samples had a percentage removal of higher than 80%. On average, the removal percentage of TSS for all seven samples was 85.6%. Membrane microfiltration increased the TSS removal. In samples 3 and 5, the concentration of TSS was reduced after membrane microfiltration. These results were supported by previous research (Sandoval *et al.* 2019), which finds that microfiltration is highly efficient in removing TSS.

Bamboo activated carbon adsorption improved the turbidity within the range of 64% to 100%. The average percentage removal of turbidity for all seven samples was 86.1%. Membrane microfiltration improved the turbidity for samples 2 and 4. After the membrane microfiltration, more than 80% of turbidity from these two samples was removed. Thus, membrane microfiltration could improve the turbidity and remove the TSS for contaminated river water.

A clear pattern was observed for the percentage removal of NH3-N. A low concentration of NH3-N, less than 0.1 mg/L in samples 1, 5, 6, and 7 was removed through the adsorption process. However, the adsorption process cannot remove the higher concentration of NH3-N found in samples 2, 3, and 4 with 0.17 mg/L, 0.21 mg/L, and 0.33 mg/L, respectively. However, membrane microfiltration could remove all NH3-N contaminants in water samples 2, 3, and 4 effectively and efficiently.

After bamboo activated carbon adsorption, the DO concentration of all samples decreased due to the reaction between DO and the bamboo activated carbon. There was also a slight drop in the DO concentration during membrane filtration for all samples.

All the pH levels of the water samples met the Class I requirements, with the minimum pH value of 6.87 and the maximum value of 7.74. After each stage of treatment, the pH level slightly increased after each treatment stage. After the three stages of treatment, the pH of all samples still met Class I of the NWQS of Malaysia, with the highest pH value of 8.03 and the lowest value of 7.33.

Table 5. River Water Quality Before and After Treatment

				Parameter				
				TSS (mg/L)	**Turbidity (NTU)**	**DO (mg/L)**	**NH_3-N (mg/L)**	**pH**
Sample	1	**Treatment Stage**	Raw	76	86	8.68	0.04	7.31
			Adsorption	4	6	2.23	0	7.43
			Filtration	2	4	2.05	0	7.61
			Disinfection	2	3	2.72	0	7.68
	2		Raw	32	36	7.69	0.17	7.74
			Adsorption	3	13	2.92	0.08	7.86
			Filtration	0	4	2.74	0	7.89
			Disinfection	0	3	3.01	0	7.94
	3		Raw	9	15	7.18	0.21	7.04
			Adsorption	3	0	2.67	0.14	7.27
			Filtration	0	0	2.53	0.02	7.41
			Disinfection	0	0	2.89	0.01	7.55
	4		Raw	21	24	6.31	0.33	7.12
			Adsorption	4	6	2.57	0.21	7.48
			Filtration	2	4	2.53	0.06	7.50
			Disinfection	2	3	3.00	0.04	7.58
	5		Raw	39	57	8.10	0.09	7.22
			Adsorption	10	11	2.38	0.01	7.68
			Filtration	3	0	2.46	0	7.81
			Disinfection	2	0	2.63	0	8.03
	6		Raw	9	11	2.95	0.02	6.87
			Adsorption	0	0	2.00	0	7.20
			Filtration	0	0	2.28	0	7.26
			Disinfection	0	0	2.65	0	7.33
	7		Raw	64	75	5.14	0.08	7.43
			Adsorption	5	9	2.28	0	7.51
			Filtration	0	0	2.42	0	7.79
			Disinfection	0	0	2.51	0	7.96

Notes: Raw means no treatment; Adsorption treatment stage consists of coagulation, settling and adsorption processes; Filtration treatment stage consists of coagulation, settling, adsorption and filtration processes; Disinfection treatment stage consists of coagulation, settling, adsorption, filtration and disinfection processes.

Rainwater treatment

Table 6 shows the results obtained from the treatment of rainwater samples through microfiltration using a 0.45 µm membrane, followed by exposure to UV radiation. Rainwater samples collected from the roof were generally very clean, with most raw rainwater samples being in Class I, except for Sample 7. NH3-N was not detected in all raw rainwater samples due to the absence of ammonia compounds from the roof. After treating through the first stage of membrane microfiltration, Sample 7 achieved Class I as the turbidity was reduced below 5 NTU. Due to the high efficiency of membrane microfiltration and considerably low levels of containments in rainwater, the contribution from UV disinfection was marginal in improving water quality. However, the DO concentration decreased after passing through membrane microfiltration. Membrane filters had obstructed DO from passing through the membranes (Lee *et al.* 2020).

Table 6. Results from the Treatment of Rainwater Samples

				Parameter				
				TSS (mg/L)	**Turbidity (NTU)**	**DO (mg/L)**	**NH_3-N (mg/L)**	**pH**
Sample	1	**Treatment Stage**	Raw	2	3	8.68	0	8.09
			Filtration	0	0	2.98	0	7.55
			Disinfection	0	0	3.51	0	7.66
	2		Raw	3	4	6.44	0	7.75
			Filtration	0	0	2.57	0	7.41
			Disinfection	0	0	2.90	0	7.43
	3		Raw	1	5	7.93	0	8.06
			Filtration	0	4	2.55	0	7.96
			Disinfection	0	0	2.85	0	7.90
	4		Raw	3	2	8.72	0	7.83
			Filtration	0	0	3.06	0	7.51
			Disinfection	0	0	3.33	0	7.59
	5		Raw	3	3	7.14	0	8.05
			Filtration	0	0	2.60	0	7.53
			Disinfection	0	0	2.88	0	7.82
	6		Raw	0	3	7.55	0	7.94
			Filtration	0	0	2.36	0	7.70
			Disinfection	0	0	2.51	0	7.76
	7		Raw	2	6	6.61	0	8.16
			Filtration	1	0	2.80	0	7.66
			Disinfection	0	0	3.06	0	7.73

Notes: Raw means no treatment; Filtration treatment stage consists of filtration process only; Disinfection treatment stage consists of filtration and disinfection processes.

CONCLUSIONS

1. As a result of high average annual rainfall, the reliability ratio of a 2.0 m^3 rainwater storage tank modelled using NAHRIM Tank (Tangki NAHRIM) surpassed a minimum of 80%, achieving 84.5%, indicating rainwater harvesting can supply 84.5% of total water demand and it is sustainable.
2. The rainwater could have been supplied for 3044 days from 2010 to 2019, with the remaining 608 days (15.5%) to be supplied with river water. Raw water samples were successfully treated to achieve Class I water quality for suitable potable usage, under

the NWQS of Malaysia.

3. The increment of tank size from 2m^3 to 2.5 m^3 will increase the reliability ratio by 3%. However, the price for 2.5 m^3 tank size is much expensive. Hence, the best size of the rainwater harvesting tank is judged to be 2.0 m^3 in this case study.
4. Raw river water samples were highly polluted, with the initial water quality in Class II, indicating extensive treatment was required. The three water treatment methods were bamboo activated carbon adsorption, membrane microfiltration, and UV disinfection.
5. Raw rainwater samples were less polluted than river water, with most having an initial quality of Class I except for one sample. NH_3-N was not detected in the water sample. Two simple water treatment methods of membrane microfiltration and UV disinfection were adequate in achieving Class I.
6. Overall, all water samples achieved Class I at the end of treatment. This research has successfully developed an integrated dual water supply system that is cost-efficient and can be installed much more efficiently at homes, especially for rural residents. It will help the SAWAS initiative to achieve 100% clean water supply coverage by 2025 at a faster pace.

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