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Development of an Integrated System for Ozone Treated Harvested Rainwater in Perspective of Green Building Scenario of Malaysia

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Abstract
In this study an integrated system for rainwater harvesting and ozone treatment has been developed for continuous supply of drinkable water. In the perspective of Malaysian scenario ozone treatment of rainwater is still considered a new approach. This pilot project is launched to justify the reliability, the effectiveness and the economic aspect of ozone treated rainwater. The samples of rainwater were analyzed for both physiochemical and microbiological parameters before and after the ozone treatment. The injection of ozone has shown prominent improvement in both parameters and also the quality up gradation of the original rainwater. The results are encouraging and suggest that the technique is promising to fulfil both requirements continuous supply of rainwater as well as accomplish successful ozone treatment. The system can readily be installed at any location and measurements assure that it could certainly provide an alternative water source when conventional piped supply is unavailable. In the perspective of Green Building scenario this integrated approach of ozone treated harvested rainwater might be able to reduce the impact of environmental factors.
Keywords: Ozone treatment, Rainwater quality improvement, Water quality, Disinfection with ozone, Green building concept.

1. Introduction

In the recent scenario the demand of water resources has an increasing trend year by year due to the population growth and expansion in urbanization, industrialization and irrigated agricultural. Adopting the concept of sustainability and conservation of water resources can help to cope with the global water shortage. Rainfall is a great blessing and is an important element of natural resources of a country. The optimum use of natural resources can provide boost to the economy of a country. On the other hand it has a severe effect on the sustainability of environment. Considering these facts the Green building concept brings together a vast array of practices and techniques to reduce and ultimately eliminate the impacts of buildings on the environment and human health. It often emphasizes taking advantage of renewable resources, e.g., using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and for reduction of rainwater run-off. The concept of Green building can also be implemented to overcome the water shortage problem through rainwater harvesting system. The quality and quantity of collected rainwater varies area to area depending on the geographic location and it has a huge potential as an alternative water source for the future [1].

Rainwater is the primary source of all drinking water and it is unlimited source on the planet. As among the countries which is located at equator zone, Malaysia has received abundant of rain in a year and suit to build a rainwater harvesting system which is a practice of collecting the water produced during rainfall events before it has a chance to run off into a river or stream or soak into the ground and become groundwater. Unfortunately, it was neglected and a large quantity of rainwater has been wasted without any serious effort to collect them. However, with the introduction of the green building concept has opened the opportunity towards harvesting the rainwater as part of the sustainable development [2]. This policy hopefully will trigger the awareness among peoples living around that region on the collecting and the utilization of rainwater for outdoor and domestic used. However, rainwater becomes polluted due to many environmental factors and is not suitable for potable purposes without treatment. Rainwater harvested from roofs can contain animal and bird faces, mosses and lichens. Besides, it also contains windblown dust, particulates from urban pollution, pesticides, and inorganic ions from the sea (Ca, Mg, Na, K, Cl, SO4) as well as dissolved gases (CO2, NOX, SOX). The water may need to be analyzed properly, and used in a way appropriate to its safety [3, 4].

The method of ozone treatment of rainwater is considered environmental friendly for water treatment because it does not require the addition of chemicals or energy for heating [5]. The ozone (O3) is produced from oxygen and it reverts back to oxygen (O2) after treatment. The ozone is 15 times more powerful than chlorine and works 3000 times faster. Ozone destroys bacteria, spores, microbes and enzymes on contact, which ensures the water is safe for reuse. Good filtration is required to remove suspended solids and by-products once before the water is treated with ozone [6]. Ozone is unstable gas at the temperature and pressures encountered in water. It has a characteristic and pungent odour which is not offensive under controlled situation. In the earth's stratosphere, ozone is formed through photochemical decomposition of certain transient air pollutants and through lightning activities. Ozone is effective over a wide pH range and rapidly reacts with bacteria, viruses, and protozoas and has stronger germicidal properties compared to chlorination and has a very strong oxidizing power with a short reaction time. With the appropriate concentration, it is also can eliminate a wide variety of inorganic, organic and microbiological problems, taste and odour problems. The microbiological agents include bacteria, viruses, and protozoas (such as: E. coli, total coliform Giardia and Cryptosporidium). The use of ozone in water treatment, thus eliminate the need to use chemical such as chlorine into water [7].

In the perspective of Malaysian scenario the ozone treatment of rainwater is considered new approach in Malaysia. In most cases, people just collecting the rainwater without treatment especially in the rural area such as Island and remote area. Malaysia is surrounded by many beautiful Island such as Tioman Island, Sibu Island, Pangkor Island and many more. Their source of water mostly came from ground water. The introduction of ozone treatment for rainwater may somehow provide another alternative source of water and also provide health safety of rainwater that perhaps being used for drinking especially to the rural area. This pilot project is conducted in order to justify the reliability, the effectiveness and the economic aspect of ozone treated rainwater harvesting to support the green building concept in Malaysia focused mainly to rural area.

In this study an integrated system is successfully developed for ozone treatment of harvested rainwater to provide continuous supply of drinkable quality of rainwater. The results suggest that the quality of treated rainwater is consistent with the Water Quality Guideline' based on Ministry of Health, Malaysia 2009. The results of physiochemical and microbiological parameters also suggest that system is feasible to provide good drinkable quality of rainwater. Moreover it can be used for the domestic use and potable uses to meet the increasing environmental challenges of pollution and unavailability of good quality of water resources.

1.1 Scope of Rainwater for Malaysia

Malaysia has a tropical climate and enjoys with plenty of rain throughout the year. The country is governed by two monsoon regimes namely the southwest monsoon which usually will be occurred in between May and September as well as the northeast monsoon which arrives around November and retreats in March. During the northeast monsoon season, the exposed areas like the east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah experience heavy rain. The Malaysia is progressing since independence (1957) and has gone rapid structural changes in the current decades which demand clean and drinkable water supply as per the growth rate of population. Even the Malaysia has abundant resources of water /rainwater but the danger of water shortage exist as faced by Malaysia in 1998. The reason of this serious water crisis was the drought season due to climate changes around Klang valley area. In Malaysia the coverage of piped supply water in rural areas is more than 95 percent and for urban areas 99 percent which unfortunately perhaps a hurdle in the development of rainwater harvesting system [Che-Ani A.I et al, 2009]. By the blessing of God Malaysia receives plenty of rainfall throughout the year as due to its geographical location that lies in a wet equatorial climate zone. In fact, there is no dry zone in whole season of Malaysia and average rainfall reach around 3,000 mm a year – Peninsular Malaysia averaging 2,420 mm; Sabah averaging 2,630 mm and Sarawak averaging 3,830 mm. The main rainy season in the east continues between November and February and August is the wettest period on the west coast. East Malaysia has heavy rains (November to February) in Sabah and in Sarawak [Che-Ani A.I et al, 2009].

2. Materials and methods

2.1 Site location and roof catchment details

This study was conducted in Taman Teratai, Skudai, Malaysia, where the mean annual rainfall is 2221.25 mm between 2008 to 2011 [8]. The site is located at residential area and far away from major industrial precinct. The type of clay roof catchment was involved in this research. Both catchments measure approximate 6 x 7 m and 8 x 7 m with tree branches which were staked to each other.

2.2 Rainwater sampling devices and systems

The rainwater harvesting system consists of the following components and elements:
(1) catchment area; (2) conveyance; (3) roof washing; (4) untreated water storage tanks; (5) treated water storage tanks; (6) distribution system; and (7) purification which means ozonation (Fig. 1).

During rainfall event (Fig. 2), rainwater was collected from the roof through gutter. The initial shower of rainfall (containing the majority of the contaminants) running off the roof washes into the first flush tank where it is retained. The first flush volume was designed as per literature [9] which state that the first flush should divert based on the rainwater catchment area. In this research, the volume of first flush was approximate

82 litters. When this down pipe becomes full due to the first flush tank, the flow of water will automatically divert to another junction and entered the sand filter tank (Fig. 3). The purpose of the buoyant sphere is to separate the initial of rainwater from mixing it in other storage tank while the sand filter commonly used to remove flock from coagulated waters. They may also be used to reduce turbidity (including adsorbed chemicals) and oxidized iron and manganese from raw waters. After the both processes, the rainwater is collected into the collection tank which is located at the bottom of the sand filter tank. The volume of collection tank used is around 300 litters while the size of the storage tank (untreated) is approximately 5000 litters. The collected rainwater is then transferred into first storage tank (untreated) using pump which is located on tank on the roof.
In the processes of distribution, at first it can be used directly for WC and non-potable purposes such as toilet flushing and cleaning. As mentioned before, the existence of microbial and chemical elements it is not suitable for potable uses. In the second stage it is distributed into contact tank via filtering process using compact filter for filter out the impurities from untreated storage tank. The contact tank performs two functions first it circulate rainwater for filtering purpose secondly it is used for ozone treatment (ozonation) around 20-30 minutes. The circulation process is performed by recycle pump which are fitted at the inlet and outlet of contact tank. Finally, the treated rainwater is stored into second storage tank (clean) which is distributed to ablution section. The size of treated storage tank is lower than untreated tank which is around 850 litters. This is because the purpose of treated storage tank is just for ablution activity.

2.3 Analytical methods

The samples of harvested rainwater were collected from roofs on 31st January to 24th May 2012 in Taman Teratai, Skudai, Malaysia. The analysis of each rain events was conducted into three categories: (1) first flush (2) untreated and (3) treated. Elemental analyses were carried out in accordance with the ‘Raw Water Quality Guideline’ and ‘Treated Water Quality Guideline’ based on Ministry of Health, Malaysia 2009 [10], and conducted within 14 days of sample collection. Microbiological analyses were commenced within 24 hours of each rain event while samples collected to assess chemical parameters were frozen for later analysis.

2.4 Microbiological Analysis

Two types of microbiological analysis were performed which are commonly cited in literature [11]: (1) Total Coliform analysis and (2) Escherichia Coli analysis which is commonly known as E. Coli analysis. For the detection and enumeration of all examined microorganisms, the relevant International Organization for Standardization (ISO) standards was followed. In detail, for total coliform and E. coli the ISO 9308-1 was followed. The detection limit of the MPN method is 0 CFU/100ml for both analyses.

3. Chemical Analysis

After the sampling process using multi parameter water quality meter (YSI Professional Series) pH value, ammonia and total dissolved solids (TDS) were measured immediately. Chemical analyses were conducted according to the standard methods for the examination of water and waste water [11] and included the determination of main anions, cations, heavy metals and organic pollutants as well as physical parameters. The determination of heavy metals and cations was carried out by atomic absorption spectrometer techniques (Perkin-Elmer model Analyst 400 equipped with HGA 900 graphite furnace), in flame or flameless mode, depending on element.

Anions and physical parameters (colour and turbidity) was conducted by spectrophotometer instrument (DR 4000U). Other physical parameter like total organic carbon (TOC) was analyzed by TOC analyzer (Shimadzu TOC V Series). For Chemical Oxygen Demand (COD) was tested (EPA method 410.4) using ultra low range (ULR) reagent measured by a COD reactor (HACH DRB 200) coupled by spectrophotometer instrument (HACH DR 5000) while Biological Oxygen Demand (BOD5) was tested (EPA method 405.1) by dissolved oxygen meter (YSI 5000). The WQI analysis is done using software provided by NAHRIM [12].

Organochloride pesticides (OCPs) analysis was performed by two processes. First process was performed by gas chromatography flame ionization detector (Agilent Technology GC FID 6890N) and second process was performed by gas chromatography mass selective detector (Agilent Technology GC MSD 5973i). Both were done after liquid- liquid extraction process (EPA method 3510C).

4. Results and Discussion

4.1 Microbiological Analysis

4.1.1 E. Coli and Total Coliform

The E. coli and Total Coliform analysis was done with three different concentrations of ozone for treatment process which is between 400 mV and 550 mV. In the first flush sample, only one sample is analyzed for reference and comparison with other samples. All these results are illustrated in Table 1.

It was observed that organisms of E. coli were extremely present in first flush of rainwater which are mentioned in Table 5.1. It was also observed that the existence of E. coli was reduced significantly in rainwater after passing through the first flush system. It means that the first flush system function is necessary and works effectively. The comparison between untreated and treated is depicted in Figure 5 which elaborate that there is not much difference during ozone concentration at 400 mV and the E. coli amount still exists at that moment. As ozone concentration increased to between 450 mV and 500 mV, the E. coli was eliminated completely. It is shown that the ozone concentration at 450 mV is enough to eliminate the E. coli.

The results depicted in Table 5.1 that the organisms of total coliform still have a high rate as compare to first flush and untreated rainwater including rainwater collected through the first flush system. The Figure 6 show that the amount of total coliform has been reduced slightly after treatment process at 400mV, 450 mV and 500 mV but total coliform still exist at the end of the process. These results show that ozone concentration is not enough to eliminate completely the existence of total coliform which need to be increased. It also suggests that for complete elimination of total coliform the effective ozonation is necessary by increasing ozone concentration to meet the required standards for both parameters.

4.2 Chemical Analysis

The chemical analysis consist of pH, TDS, DO, Ammonia, Total Chlorine, Chromium, Cyanide, Copper, AN, COD, BOD, TSS and TOC. The results of Figure 7 show that most of the parameters for both conditions are below standard of raw water guideline [10]. In first flush condition of rainwater samples only two parameters COD and BOD are not as per the requirement of standard values. The reading level of COD and BOD is high may be due to influence of atmospheric condition such as heavy dust during the rainfall events, roofs condition, material used, birds and insects dropping on roofs. For TOC, ammonia, chromium and cyanide analysis, the value is approx to zero. The result may have been influenced due the site is located at residential area and far away from major industrial precinct.

However this chemical analysis for treated rainwater can be ignored because of the results depicted at Figure 5.2 which shows that all of the parameters are found below the standards during untreated condition of rainwater (post-first flush system).

4.3 THMs and OCPs Analysis

THMs and VOCs were not detected in any sample of rainwater. Location of the site project is relatively pure from traffic emissions, industrial and agricultural wastes. This fact is validated by the absence of organic contaminants which are THMs and OCPs [13]. Moreover, the existence of most of THMs is from the chlorination disinfection process. Thus, using ozone disinfection, the existence of THMs is may be very low or absent in any sample.

4.4 WQI Analysis

Based on Table 3, classification of water for first flush condition is at Class II. That means the water is just for recreational use with body contact such as swimming, windsurfing, water-skiing, boating and fishing. At this class, the rainwater is not suitable for water supply. Thus, it is shown the first flush is really needed in roof based harvesting system due to its good characteristic. While classification of water for untreated and treated rainwater condition is at Class I which means the water is suitable for water supply. Thus, it is shown that both storage tanks are safe to supply the water at Surau Raudatul Jannah, Taman Teratai in Skudai. However, bear in mind that the water is not for potable purposes. As discussed previous, there is still having microbial organisms. It means that the water is totally not suitable for potable purposes. So, the water is only suitable for non-potable purposes such as cleaning and washing purposes.

5. Conclusion

In this study of rainwater harvesting and treatment of rainwater by ozone has been performed successfully and results confirm that it could provide alternative source for high grade water source when a conventional piped supply is unavailable, unreliable or too expensive. It has a capability to provide good quality rainwater for potable uses to meet the future challenges of environmental pollution. The integrated harvesting system has the provision for in situ water treatment as per requirement of water. The results suggest that it has the capability to fulfill continuous supply of drinkable quality of ozone treated rainwater. The worked performed also visualize the future infrastructure in perspective of green building concept, which would be equipped with rainwater harvesting system. The proposed system is also compatible to the Green Building concept of Malaysia as it can be applied in both urban and rural areas for the sustainability of environment.

Overall, demonstrated results ensure that the ozone treated rainwater could be used as supplementary water source in future infrastructures around the globe where annual rainfall is quite high. By implementing the ozone treatment system integrated with rainwater harvesting system, not only provide health safety but also save the economic resources. It also gives assurance about the drinkable quality of rainwater by reducing the level of many impurities in the water including odour and taste due to attributes of ozone as a powerful oxidizing agent. In addition, the results suggest that ozone disinfection technique can also reduce the microbial contamination of rainwater and appeared reliable to provide alternative water source in future.

Nomenclature

BDOC	biodegradable dissolved organic carbon
BOD	biological oxygen demand
BOM	biodegradable organic matter
COD	chemical oxygen demand
CFU	colony-forming unit: amount of a culturable organism required to form a single colony on culture media
DBP	Disinfection By-Products
DOC	dissolved organic carbon
E.coli	Escherichia coli
GAC	granular activated carbon
HAA	haloacetic acids
NAHRIM	National Hydraulic Research Institute of Malaysia
NOM	natural organic matter
NOX	Nitrogen Oxide
NTU	nephelometric turbidity units
NTP	normal temperature and pressure, 0 C or 273 K and 1 atm,
(OCPs)	Organochloride pesticides
THM	trihalometanes, MCL of 0.10mg/L to 0.080mg/L, proposed
TOC	total organic carbon
UV-254	Ultra Violet absorbance at 254 nm
VOC	Volatile organic compound

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Captions for Figures

Fig. (1): (A) Components of RWH
(B) First Flush System
(C) Complete Unit Rainwater Purification System
Fig. (2): Rainwater System Layout
Fig. (3): (a) E. Coli Analysis (b) Total Coliform Analysis
Fig. (4): Chemical Analysis
Table 1: Microbial Analysis
(Rain events between 17th May 2012 and 24th May 2012)
Table 2: Chemical Analysis
(Rain events between 17th May 2012 and 24th May 2012)
Table 3: Water Quality Index (WQI)
(Rain events between 17th May 2012 and 24th May 2012)

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Table 1: Microbial Analysis (Rain events between 17th May 2012 and 24th May 2012)

Parameter	Ozone Concentration (ORP) 400-450 mV			Ozone Concentration (ORP) 450-500 mV			Ozone Concentration (ORP) 500-550 mV		
	Sample (MPN)			Sample (MPN)			Sample (MPN)		
	First Flush	Untreated	Treated	First Flush	Untreated	Treated	First Flush	Untreated	Treated
Total Coliforma	2112	437.4	104.1	2112	322.5	113.3	2112	207.7	119.4
E. Colia	2112	82.2	56.5	2112	70.25	0	2112	58.3	0

a Drinking Water Guidelines (Ministry Of Health Malaysia)

Table 2: Chemical Analysis (Rain events between 17th May 2012 and 24th May 2012)

Parameter	First Flush				Untreated				DWG**
	1	2	3	Mean	1	2	3	Mean	
pH1	7.5000	7.4400	7.3900	7.4400	7.8300	7.5400	7.5100	7.6267	6.5-9.0
Total Chlorine1 (mg/l)	0.2000	0.2000	0.2000	0.2000	0.2000	0.1000	0.1000	0.1333	1.00
Total Dissolved Solids2 (mg/l)	0.0481	0.0195	4.0300	1.3659	0.0871	0.0247	0.0253	0.0457	1000
COD2 (mg/l)	24.0000	29.2000	22.1000	25.1000	3.9000	0.4000	1.0000	1.7667	6.00
BOD2 (mg/l)	6.8250	7.2500	5.5250	6.5333	0.7000	0.1400	0.3400	0.3933	10.00
Total Organic Carbon2 (mg/l)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-
Ammonia3 (mg/l)	0.0100	0.0100	0.0000	0.0066	0.0000	0.0100	0.0000	0.0000	1.5
Chromium3 (mg/l)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0100	0.0000	0.0033	0.05
Cyanide3 (mg/l)	0.0430	0.0120	0.0275	0.0275	0.0340	0.0040	0.0380	0.0253	0.07
Copper3 (mg/l)	0.0400	0.0500	0.0500	0.0467	0.0400	0.0400	0.0400	0.0400	1.00

** Drinking Water Guidelines (Ministry Of Health Malaysia)

Table 3: Water Quality Index (WQI) (Rain events between 17th May 2012 and 24th May 2012)

Parameter	First Flush	Untreated				Treated			
		1	2	3	Mean	1	2	3	Mean
Ammoniacal Nitrogen (mg/l)	0.108	0.094	0.088	0.088	0.09	0.096	0.025	0.052	0.06
BOD(mg/l)	7.20	0.83	0.34	0.14	0.44	1.01	0.21	0.53	0.58
COD (mg/l)	22.10	2.50	1.00	0.40	1.30	3.10	2.50	1.60	2.40
Dissolved Oxygen (mg/l)	5.93	8.07	8.19	7.00	7.75	8.78	9.04	8.89	8.90
pH	7.39	7.83	7.51	6.93	7.42	7.69	7.41	7.63	7.57
TSS (mg/l)	13.00	4.00	5.00	6.00	5.00	2.00	0.00	0.00	0.67

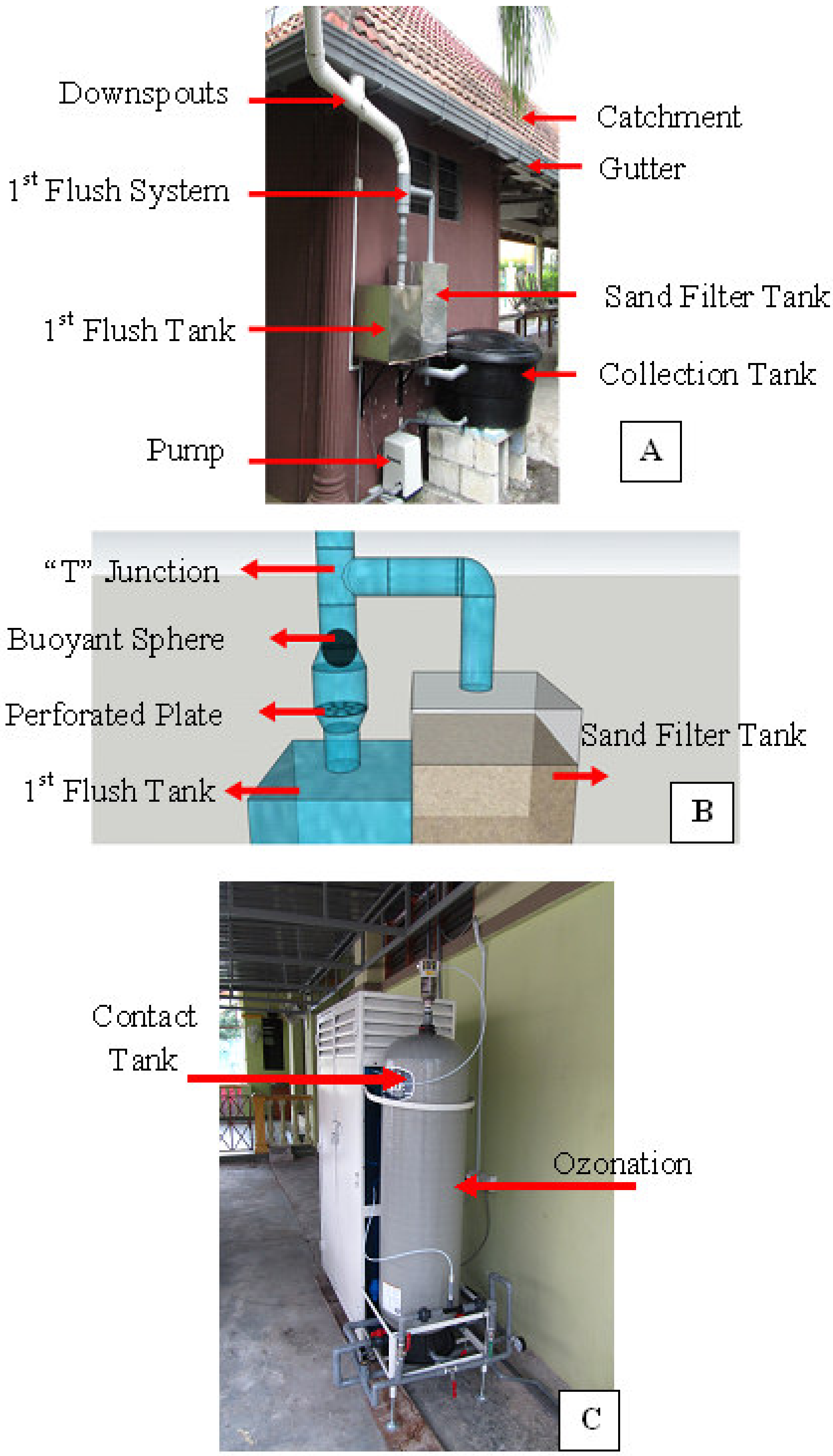


Fig. 1: Actual System Woking in Surau Raudatul Jannah, Taman Teratai in Skudai, Malaysia.
(A) Components of RWH (B) First Flush System
(C) Complete Unit Rainwater Purification System.

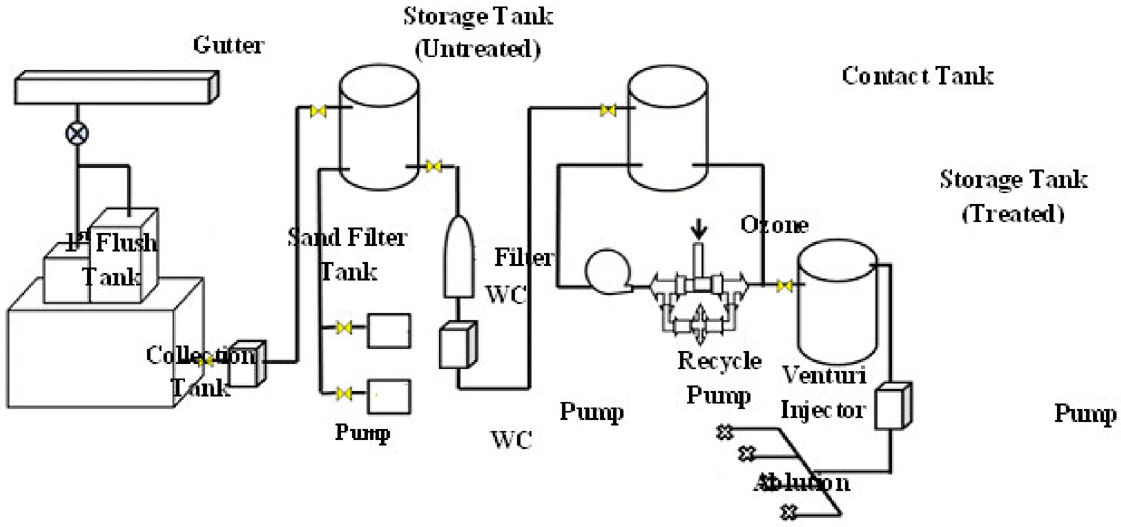
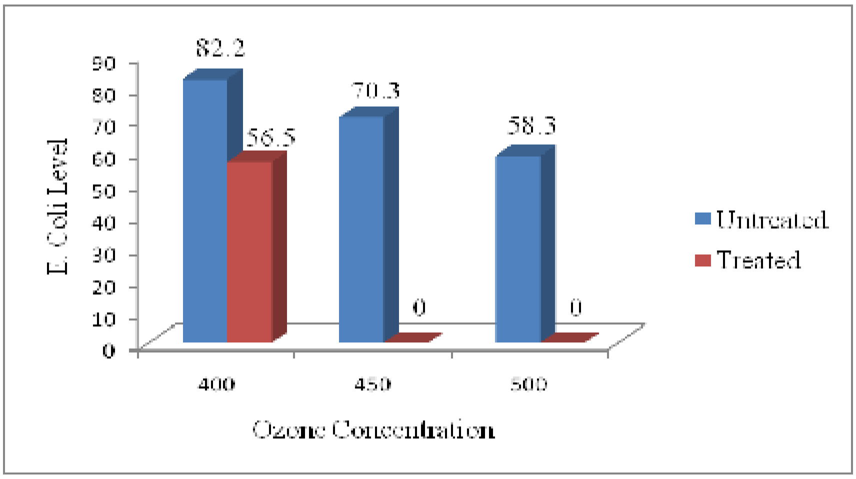


Fig. 2- Schematic Diagram of Rainwater Harvesting and Treatment System



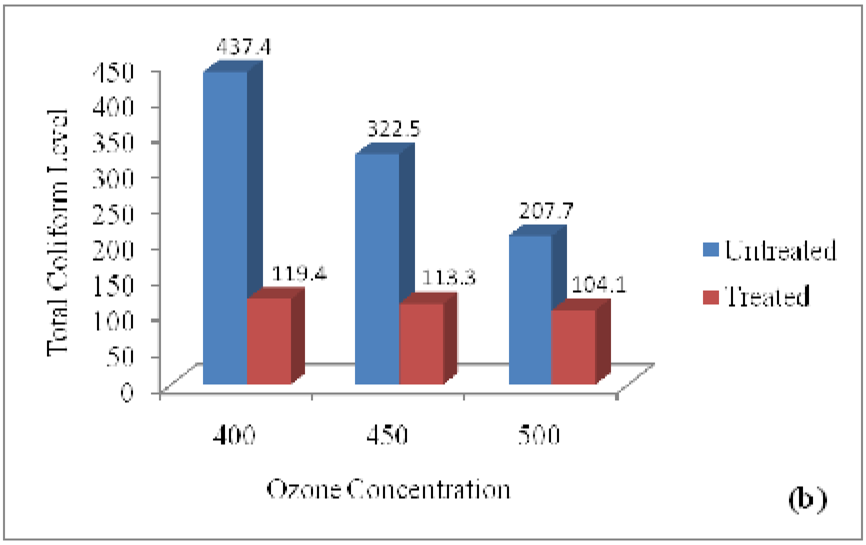


Figure 3: (a) E. Coli Analysis (b) Total Coliform Analysis

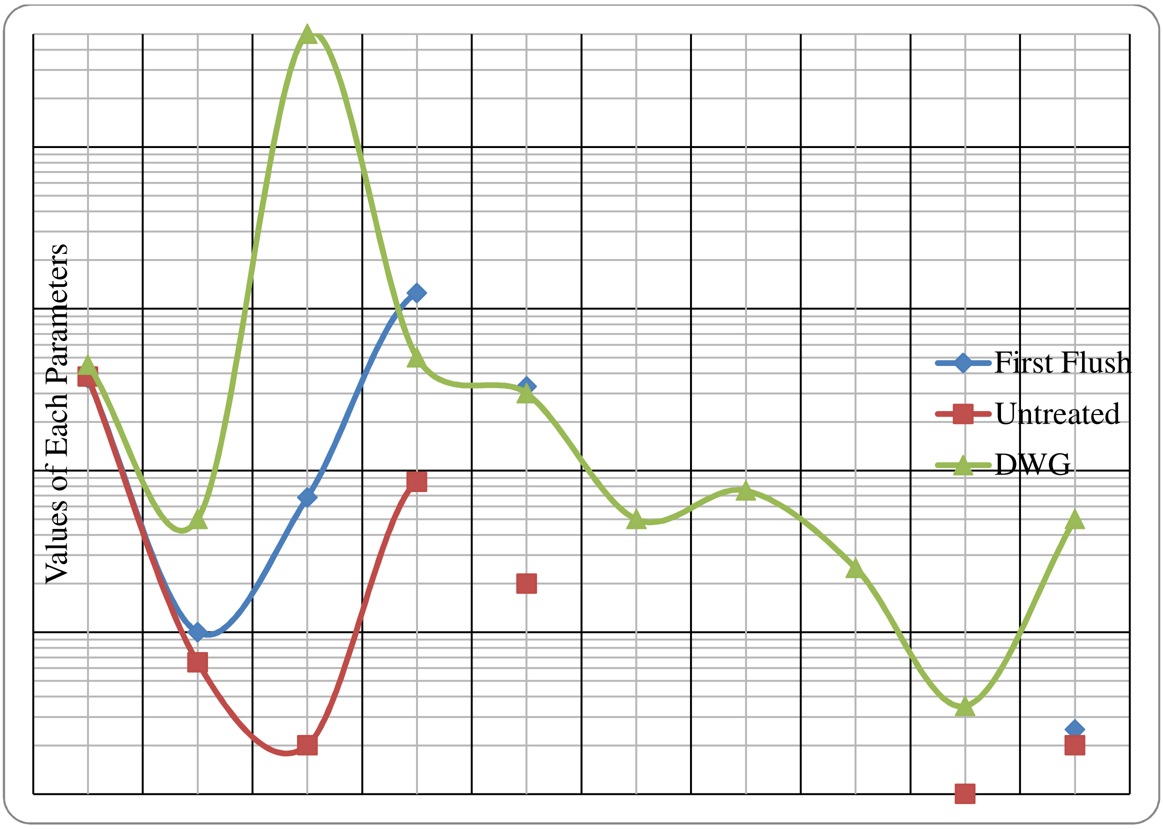


Figure 4: Chemical Analysis