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# RAINWATER HARVESTING QUALITY ASSESSMENT AND EVALUATION: IIUM CASE STUDY

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***ABSTRACT:*** This study focuses on rainwater harvesting quality at the Faculty of Engineering, International Islamic University Malaysia (IIUM). As development is progressing over the years in Malaysia, there is also an increasing number of environmental issues and those issues are getting worse day by day. At present, Malaysia is blessed with plentiful annual rainfall that represents approximately 314 mm of monthly rainfall but there is no evidence that this rainwater is redirected for daily usage. To pursue a more sustainable development, rainwater harvesting has been recognized as one innovative solution. The IIUM Gombak campus is located in a hillside area that is a suitable study area to perform rainwater harvesting, which can be used as an alternative water supply in the future and reduce utility bills for water used on the campus. Firstly, a suitable study area for rain water harvesting around KOE, IIUM was determined before collection of data to determine the storage capacity needed. This study includes the estimation of rainwater quantity that can be harvested in one year. The quality of rainwater in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, total suspended solid (TSS), turbidity, and microbial count were studied. Data analysis showed that the values of BOD, COD, pH, TSS, turbidity, and microbial count were in the range of 2 - 3.2 mg/l, 22.5 – 42.5 mg/l, 5.9 - 6.5, 20 mg/l, 9 -11 NTU, and between 200 - 260 cfu/ml, respectively. This indicates that the harvested rainwater is acceptably clean but not suitable to be used as drinking water.

***ABSTRAK:*** Fokus kajian ini adalah pada kualiti air hujan yang ditadah di Fakulti Kejuruteraan, Universiti Islam Antarabangsa Malaysia (UIAM). Sejajar dengan pembangunan pesat di Malaysia, isu alam sekitar juga semakin bertambah dan menjadi semakin teruk hari ke hari. Pada masa sama, ketika ini Malaysia dirahmati dengan hujan yang mencurah setiap tahun, dengan kuantiti bulanan sebanyak 314 mm air hujan dan tidak ada bukti penggunaan air hujan ini bagi kegunaan harian dsb. Bagi memenuhi keperluan kelangsungan pembangunan, penadahan air hujan dikenal pasti sebagai satu penyelesaian inovatif. Kampus UIAM Gombak terletak di kawasan pinggiran bukit yang sesuai bagi menjalankan kajian tadahan air hujan. Ianya boleh digunakan sebagai bekalan air alternatif pada masa depan dan mengurangkan bil utiliti bekalan air dalam kampus. Terlebih dahulu, kawasan kajian yang sesuai dikenal pasti berdekatan Fakulti Kejuruteraan, UIAM bagi mengumpul air hujan sebelum data dikumpulkan bagi mengenal pasti kapasiti pengumpulan yang diperlukan. Kajian ini juga menganggar kuantiti air hujan yang boleh ditadah dalam satu tahun. Kualiti air hujan dikaji dari segi keperluan oksigen biokimia

(BOD), keperluan oksigen kimia (COD), pH, jumlah pepejal terampai (TSS), kekeruhan dan bilangan mikrob. Analisis data mendapati nilai BOD, COD, pH, TSS, kekeruhan dan bilangan mikrob berada dalam julat 2 - 3.2 mg/l, 22.5 – 42.5 mg/l, 5.9 - 6.5, 20 mg/l, 9 - 11 NTU dan antara 200 -260 cfu/ml, masing-masing. Ini menunjukkan air hujan yang ditadah adalah boleh diterima sebagai bersih tetapi tidak sesuai dijadikan sebagai air minuman.

***KEYWORDS:*** *rainwater harvesting; water quality analysis; Moringa oleifera; disinfectant*

# 1. INTRODUCTION

Water harvesting is a practice that has been used to increase the effectiveness of water and make use of it. Water harvesting systems direct water, from a great normal watershed or man-made collection, into a small puddling basin. The water can then be stored in subversive tanks or be used directly for irrigation or family purposes. In the modern period, water harvesting has been neglected, particularly in developed countries, due to technical achievements in the fields of water treatment and distribution. But, in recent years, water harvesting in modern-urban environments has turned into an essential practice. Municipal areas are being cemented and built, resulting in the decrease of groundwater renewal area. As a result, a great quantity of good water that rains over the municipality is inhibited from refreshing aquifers as it is absorbed into the public drainage system.

The water crisis is hitting a current civilization that already needs to decrease its major expenditures: energy utilization and water use. The sometimes indiscriminate utilization of water wealth flies in the face of water deficiencies and scarcity occurring in several countries. Less than 1% of the water on the globe is potable. The water from rain, melting snow, and fog has always been considered to have important potential to contribute to supply, even though these types of water need to be treated in order to meet the legal requirements for consumption, with chemical, microbiological, and sometimes accurate bacteriological reports. The most important factor in the planet's wellbeing report card is the quality and quantity of potable water reserves: partial accessibility, patchy distribution, and rising contamination levels are growing concerns aggravated by booming world population, increased use per capita, water mismanagement and the lowering of water aquifers due to unnecessary removal.

Ruhela [1], declared that fresh surface water is routinely restocked by rainfall, but added that the one factor that most determines the availability of good and sufficient fresh water supply is the ever-increasing population. In Malaysia, Wong [2] highlighted that in November and December, during the North-East Monsoon, Malaysia received the maximum rainfall for the year. The difference in temperatures in certain places, for example cold temperatures in central Asia, will result in a change in atmospheric pressure that causes strong winds and heavy rainfall on the east coast of peninsular Malaysia near the South China Sea. The maximum average rainfall recorded in one month is 314 mm in December, which represented 14 percent of the average rainfall for one year. This proves that Malaysia is blessed by a sufficient, accessible supply of fresh water.

Rainwater harvesting is a process for inducing, collecting, storing, and conserving local surface run off water for various purposes such as drinking, washing, and irrigation. There are 3 types of surfaces that allow the process of harvesting rainwater: rooftops, water bodies, and storm drains [3]. Several factors that need to be considered before implementing water harvesting are rainfall intensity and distribution, the type of soil and the depth of soil, water resources, infrastructure and socio-economic conditions, environmental and ecological impacts, and the terrain and topography profile [4].

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Water quality, on the other hand, generally refers to the characteristics and condition of water according to certain units of measurement. Water is divided into a few classes based on its usage and it can be determined to be good and safe for use if it meets the minimum requirements set by the Department of Environment (DOE) of Malaysia.

In Malaysia for instance, water harvesting can fulfill two purposes: to stockpile surplus water owing to rain and to supplement established water sources, usually during periods of water deficiency [2]. During droughts, water harvesting is vital to meet domestic water requirements for human use. Whether rainwater harvesting technology is used as the source of non-potable or potable water, it can be managed to supplement existing sources. In addition, the fast expansion of population is another factor aggravating water shortages. A sluggish economy paired with water scarcity causes the need for potable or non-potable water for drinking and sanitation to proportionally increase.

There are a few treatments that can be used to treat the rainwater harvested from the roofs, such as filtration and UV treatment [6]. *Moringa oleifera* seeds can be used as a disinfectant that can remove microbes in water and act as a coagulant [7]. The main objective of this study is to estimate the volume of rainwater that can be harvested from the roof of one building (E0) at the Faculty of Engineering, IIUM over the course of one year. An additional aim is to analyze and characterize the harvested rainwater in terms of BOD, COD, pH, TSS, turbidity and microbial count to determine its suitable application or usage.

### 1.1 Present Rainwater Harvesting (RWH)

RWH consists of rainwater collection from large surfaces, mainly rooftops [8,9,10], and storage of the water under or above ground in reservoirs. Based on the water quality, which is mainly affected by the quality and state of the water collection surfaces and the delivery systems, the water can be used for drinking, domestic uses, and irrigation. RWH is a renewable source of clean water that is ideal for domestic and small scale agricultural uses and the greater attraction of a rainwater harvesting system is its low cost, accessibility, and simple maintenance at the household level [11]. RWH can promote significant water saving in residences in different countries. For an example, in Germany, Herrmann [12] reported that a potential saving of potable water in a house might vary from 30% to 60%, depending on the demand and size of the rainwater collection area. In Newcastle, Australia, RWH would save 60% of potable water [13] and in Brazil, Ghisi [14] concluded that a potential water saving by using water harvesting was in the range of 34% to 92%, with an average of 69%. Abdulla [11] indicated a potential water saving of up to 20% of drinking water by applying RWH at urban environment in Jordan.

### 1.2 Water Quality Analysis

Water from any source, whether harnessed or harvested from ground water or rainwater, has its own quality. Therefore, it is important to begin by analyzing the water's quality before it can be used for drinking or for irrigation. There are many variables that make up the water quality analysis such as the total suspended solid, the chemicals present, and the oxygen demand of the water tested. It is important to determine the water quality so that a proper water treatment process can be carried out to fulfill the specific water quality requirement for a specific usage. These requirements have been set by either the Department of the Environment (DOE) or Ministry of Health (MOH) in Malaysia. In Malaysia, Juahir et al [15] asserted that, according to Malaysia's DOE (1997), there are six variables that need to be included in water quality data to develop a Water Quality Index. These six variables are dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), ammonical nitrogen (AN) and pH. The standard

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requirement of the DOE for different types of water class is shown in Table 1 and the applications allowed for each class are shown in Table 2.

Table 1: DOE Water Quality Index Classification*

| Parameter | Unit | Class | | | | |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | V |
| **Ammonical nitrogen** | mg/l | < 0.1 | 0.1 – 0.3 | 0.3 – 0.9 | 0.9 – 2.7 | > 2.7 |
| **Biochemical oxygen demand** | mg/l | < 1 | 1 – 3 | 3 – 6 | 6 – 12 | > 12 |
| **Chemical oxygen demand** | mg/l | < 10 | 10 -25 | 25 – 50 | 50 – 100 | > 100 |
| **Dissolved oxygen** | mg/l | > 7 | 5 – 7 | 3 – 5 | 1 – 3 | < 1 |
| **pH** | | > 7 | 6 – 7 | 5 – 6 | < 5 | > 5 |
| **Total suspended solid** | mg/l | < 25 | 25 - 50 | 50 - 150 | 150-300 | > 300 |

(*adapted from the National Water Quality Standards)

Table 1: DOE Water Quality Index Classification*

| CLASS | USES |
|---|---|
| **Class I** | Conservation of natural environment.<br>Water Supply I - Practically no treatment necessary.<br>Fishery I - Very sensitive aquatic species. |
| **Class IIA** | Water Supply II - Conventional treatment.<br>Fishery II - Sensitive aquatic species. |
| **Class IIB** | Recreational use body contact. |
| **Class III** | Water Supply III - Extensive treatment required.<br>Fishery III - Common, of economic value and tolerant species; livestock drinking. |
| **Class IV** | Irrigation |
| **Class V** | None of the above. |

(*adapted from the National Water Quality Standards)

## 2. MATERIALS AND METHODS

This study was conducted in three parts according to the objectives of the project. The E0 building in the Faculty of Engineering was set as the study area where the rainwater was harvested. A high density polyethylene (HDPE) tank with down pipes and conveyance pipes, depending on the site assessment and calculation of water demand, were installed in the E0 building to collect and store the harvested rainwater.

### 2.1 Preparation of Water Storage Tank

Fresh rainwater was the main raw material for this study and it was collected from the roof of IIUM's Faculty of Engineering Building (E0). A downpipe which connected with gutter of the roof was chosen to install a high density polyethylene (HDPE) tank for the rainwater storage. Figure 1 shows the location of the rainwater harvest at IIUM.

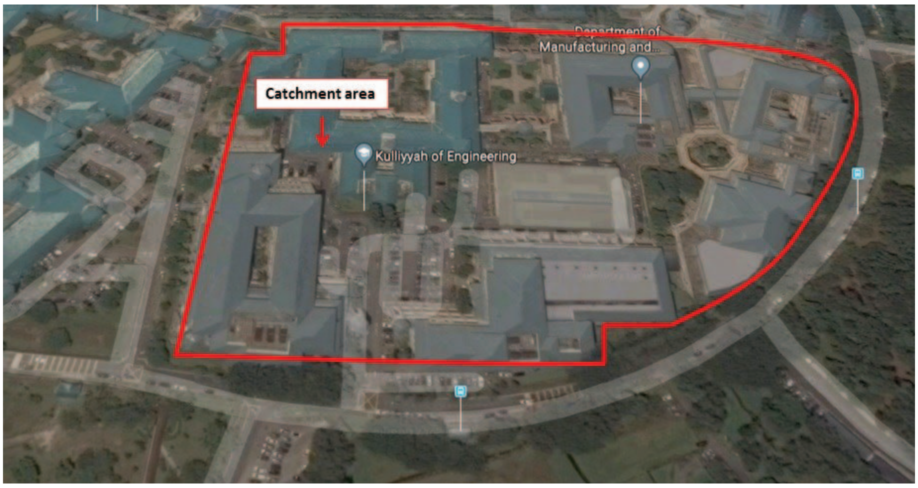


Fig. 1: The study area (adapted from https://www.google.com.my/maps).

A downpipe (Fig. 2) that connected with the gutter of the roof was used to harvest the rainwater. An HDPE tank holding roughly 80 gallons was purchased together with 3 inch polyvinyl chloride (PVC) lay-flat flexible water hose pipe for the installation of the tank. The tank was installed with a PVC water tap to collect the samples in the E0 building near the staff parking area.

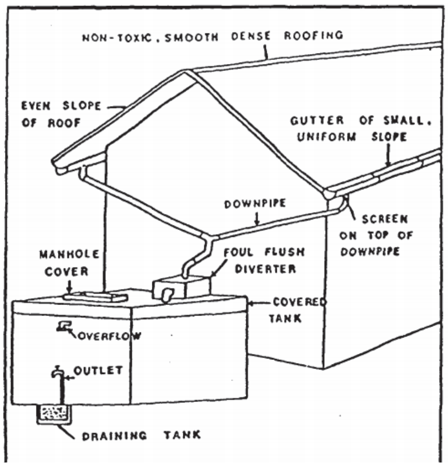


Fig. 2: Roof rainwater harvesting system.

## 2.2 Estimation of the Rainwater Quantity

The external length and width of the E0 building beneath the roof were measured, and divided into several individual rectangles. The tank was designed to meet the necessary water demand throughout the dry season. Eq. (1) was used to obtain the required storage capacity:

$$\text{Required storage capacity} = \text{demand} \times \text{dry period} \quad (1)$$

The average volume of rainwater collected in an hour of rain was calculated based on Eq. (2).

$$V_R = I \times H_{ra} \times C \quad (2)$$

Where

$V_R$ = amount of water that can be harvested ($m^3$); $I$ = rainfall intensity (mm); $H_{ra}$ = catchment area ($m^2$); $C$ = runoff coefficient.

The volume of rainfall that can be harvested from IIUM was estimated using Eq. (1). Eq. (2) can be interpreted as the volume of rainfall that can be harvested per hour and is based on the area of catchment, the rainfall intensity, and the runoff coefficient. Since this study focused specifically on rainwater harvesting by roof catchment, the data for the surface area of the roof at Faculty of Engineering E0 building and the entire roof of IIUM were obtained from the Development Division of IIUM (Table 3).

Table 3: Total surface area of roof in IIUM

| **Location** | **Surface Area of the Roof ($m^2$)** |
|---|---|
| **Faculty of Engineering** | 19,302 |
| **IIUM (Gombak Campus) All Faculties, Mahallah's and Other Buildings in IIUM** | 726,986 |

The runoff coefficient was determined from the roof's material. Different types of material used for the roof will have different runoff coefficients. Table 4 shows the runoff coefficient for the roof catchment area. Based on Table 4, the runoff coefficient for roof in IIUM was set to 0.80 since it is made of tiles.

Table 4: The runoff coefficient for roof catchment (UNEP, 2009)

| **Roof's Material** | **Runoff Coefficients** |
|---|---|
| **Tiles** | 0.8 – 0.9 |
| **Corrugated metal sheets** | 0.7 – 0.9 |

The rainfall intensity data was obtained from the on-line hydrological data from the Department of Irrigation and Drainage Malaysia for Klang Gate Dam area. From the cumulative rainfall data, the average rainfall intensity in a month is between 100-200 mm/hour taken in December as the reference. Figure 3 illustrates the hyetograph obtained for cumulative rainfall per hour for a period of a month.

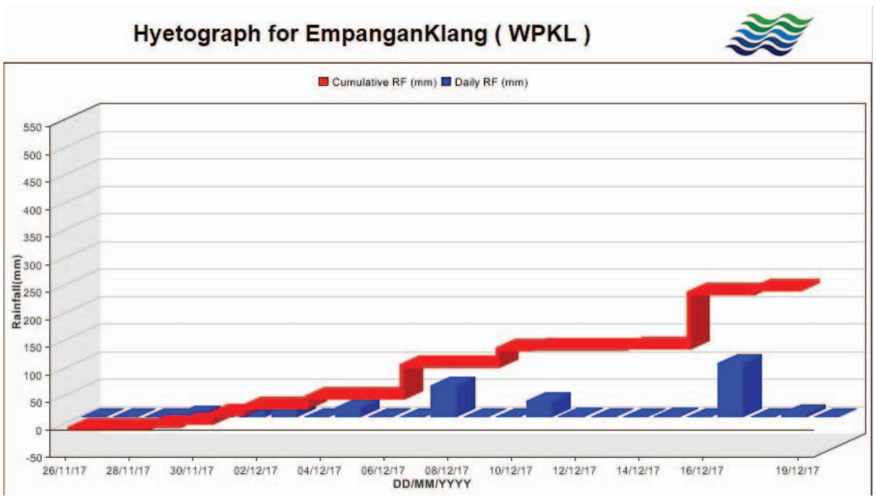


Fig. 3: Hyetograph of rainfall in Klang Gate Dam station (obtained from http://infobanjir.water.gov.my).

### 2.3 Sample Collection and Analysis

Samples were taken from a downpipe in the E0 building for every 5 minutes of rainfall over a 30-minute period. The samples were analyzed according to the parameters selected (BOD, COD, pH, TSS, turbidity and microbial count). The BOD and COD test were conducted according to the standard operating procedure by the American Public Health Association (APHA). The concentration of COD in the water was analyzed using a spectrophotometer at the 600 nm wavelength. In addition, digestion solution and sulfuric acid reagent were prepared prior to the COD analysis. The sample's pH and turbidity were both analyzed by HACH pH meter and turbidity meter. Microbial count was measured by incubating the 100 µl samples in nutrient agar for 48 hours at 37°C.

### 2.4 Preparation of *Moringa oleifera* Seeds

Dry seeds of *Moringa oleifera* were bought from a local supplier before the wings and coat of the seeds were separated manually. The seeds were grounded into powder form using a domestic blender and sieved through a 210 µm sieve. The powdered form of *Moringa oleifera* seeds was defatted using a Soxhlet extractor. About 10 g of powdered seeds was placed in the thimbles and 170 ml of hexane was poured into the thimbles as well as the solvent. It was run for 90 minutes and the powdered seeds in the thimbles were dried and weighed. The defatted powder was added into a beaker containing 1000 ml of distilled water. The solution was mixed using a stirrer at 85 rpm for different periods of mixing time set for experiment optimization [16].

#### *2.4.1 Optimization of Disinfectant Preparation*

The disinfectant preparation procedure was optimized based on two factors, the dosage of powdered seed (mg/ml) and the mixing time. The mixing speed was fixed at 85 rpm. Design Expert software was used to for experimental design and statistical analysis using a Response Surface Methodology (RSM). The percentage of bacterial removal was set as the response of this study. The dosage of seeds in the beaker was varied from 2.75 mg/ml to 3.75 mg/ml while the mixing time was varied from 21 minutes to 41 minutes [16].

#### *2.4.2 Treatment of Rainwater Using Moringa oleifera*

In each optimization run, 1 ml of *Moringa oleifera* extracts was added into 10 ml of rainwater sample. A blank sample was prepared as the control by adding 10 ml of rainwater without any disinfectant. The mixture was mixed and incubated without agitation for 2 hours. Each sample was diluted with distilled water before it was pipetted onto the agar in a petri dish. It was then incubated at 37 °C for 48 hours. The bacterial count was calculated and the data of each run was compared with the control.

## 3. RESULTS AND DISCUSSION

### 3.1 Estimation of Rainfall Quantity

The volume of rainfall that can be harvested at IIUM was estimated using Eq. (1). The equation stated that the volume of rainfall that can be harvested per hour is calculated based on the area of catchment, the rainfall intensity and the runoff coefficient. The study was done specifically on rainwater harvesting by roof catchment, thus, the data for the surface area of the roof in the Faculty of Engineering and the entire IIUM roof was obtained. The estimated volume of rainwater that can be harvested in the Faculty of Engineering and the entire IIUM (Gombak campus) is 37000 $m^3$ per year and $1395 \times 10^3$ $m^3$ per year, respectively.The result was in line with a study carried out in Sarawak that reported that water demand for their study was 4.32 $m^3$ per day.

### 3.2 Water Quality Analysis

The BOD obtained was in the range of 2.0 – 3.2 mg/l. Contamination that occurred on the roof and along the downpipe by elements such as dried leaves, dead animals, or animal waste, contributed to the high BOD. This is due to the consumption of dissolved oxygen in the water by the bacteria that degrade these contaminants. It may also be due to the contamination occurring along the downpipe being flushed exponentially in the first few minutes of rainfall.

The concentration of COD was in the range of 22.5 – 42.5 mg/l. Since IIUM is located near the Karak Highway, pollutants from the vehicles contribute to the high concentration of COD as well as chemicals from bird droppings and chemicals from the roof itself. The amount of TSS is contributed from the impurities that formed on the catchment roof and along the downpipe to the rainwater harvesting tank. The average concentration of TSS in the rainwater collected was 20 mg/l. The readings of concentration of TSS for every five minutes of samples were quite similar and since there are not many impurities in the rainwater harvested, the concentration of TSS is low. Figure 4 shows the concentration of BOD, COD, and TSS in the rainwater against the times of sampling.

The pH of the rainwater harvested in IIUM was in the range of 5.9 – 6.5. The pH value changed after a few minutes of rainfall where a low pH value was recorded in the first 10 minutes. The result indicates the rainwater is acidic in the early minutes of rainfall. This is because the first flush of rainfall carries the trapped carbon dioxide gas from vehicle activities as well as other gases in the air [4]. The average turbidity of rainwater was rather low, in which the highest recorded turbidity for harvested rainwater was 11.21 NTU. The low turbidity indicates that the clarity of rainwater is high since there are less particles or matter suspended in the water [1]. Microbial count was performed with the aim to determine the existence of microbial matter in the harvested rainwater. The recorded microbial count in 1 ml of water sample is in the range of 200 – 260 colony-forming units (CFU). This is the result of two major contamination sources: animals and the environment of the catchment area itself. These include the waste produced by birds or animals and dead organisms [6].

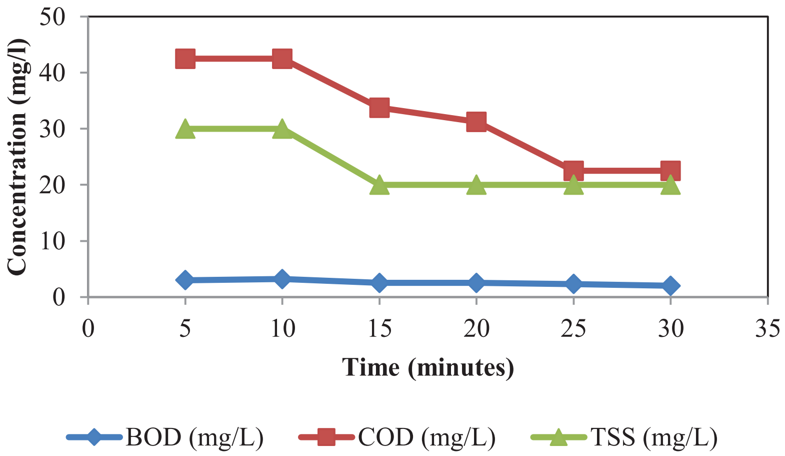


Fig. 4: The graph of water quality against time.

### 3.3 Optimization of Disinfectant Preparation

The optimization was done for the preparation of the disinfectant by using Design Expert 6.0.8. Two factors were tested by using Central Composite Design (CCD) under RSM. The aim of the optimization is to obtain the highest percentage of microbial removal by varying the mixing time and the dosage use in the preparation of disinfectant. A total of 10 runs with two central points were set for the experiment, as shown in Table 5.

Table 5: Experimental design for optimization

| Run | Mixing time (min) | Dosage (mg/ml) | Microbial removal (%) |
|---|---|---|---|
| 1 | 21 | 3.25 | 65.9 |
| 2 | 41 | 3.25 | 59.5 |
| 3 | 31 | 2.75 | 65.4 |
| 4 | 41 | 3.75 | 65.4 |
| 5 | 31 | 3.75 | 66.8 |
| 6 | 31 | 3.25 | 65.9 |
| 7 | 21 | 3.75 | 67.3 |
| 8 | 21 | 2.75 | 77.1 |
| 9 | 41 | 2.75 | 54.1 |
| 10 | 31 | 3.25 | 66.3 |

From the data obtained, ANOVA was used to represent the relationship between the parameters and the response as well as the effect of individual parameters. The final equation obtained from ANOVA is as in Eq. (3):

$$\textit{Microbial Removal (\%)} = +\,65.37 - 5.22A + 0.48B + 5.28AB \qquad (3)$$

Where, A and B are the mixing time (in minutes) and the dosage (mg/ml), respectively. The model is significant, as the Model *F-Value* was 18.23. Furthermore, the value of *Prob > F* was less than 0.05, thus proving the model was significant. The R-squared for the model was 0.9011, which means that 90.11% of total variation in microbial removal is attributed to the experimental value. Figure 5 shows the effect of both mixing time and dosage during the preparation of *Moringa oleifera* as disinfectant on the microbial removal during treatment of rainwater. De-fatted powdered seeds of *Moringa oleifera* at 2.75 g/liter of distilled water and 21 minutes of mixing time was able to achieve the best percentage of microbial removal of 75.38%. According to Suarez [17], around 2 mg/ml of *Moringa oleifera* used had the highest inhibition, which is acceptable.

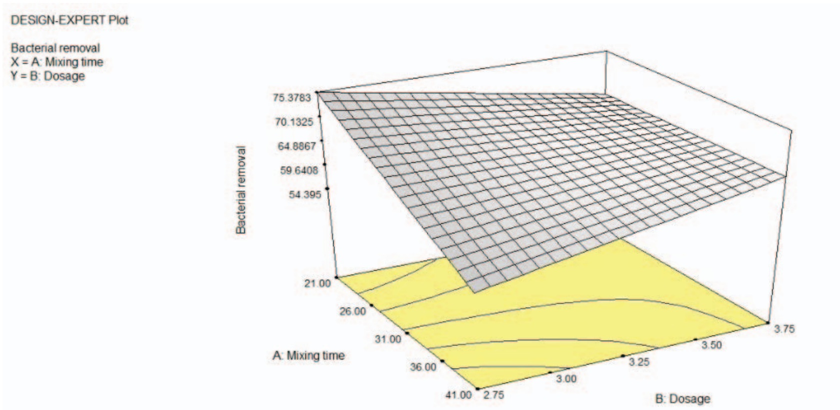


Fig. 5: Effect of mixing time and dosage on microbial removal in 3-D.

## 4. CONCLUSION

In this study, the three main objectives were to estimate the volume of rainwater that can be harvested in a year, to characterize the rainwater harvested, and to treat the rainwater using *Moringa oleifera*. The volume of rainwater that can be harvested from the roof at

IIUM is 1395 × $10^3$ $m^3$ per year. Analysis done on BOD, COD, pH, TSS, turbidity, and microbial count indicates that the rainwater complies with the Class III standard in the water quality index set by the DOE. The rainwater harvested from the rooftop is non-potable and is not safe to consume as drinking water but it is suitable to be used for gardening, flushing, or cleaning processes. From the data obtained, the quality of rainwater harvested from the rooftop improved as the time increased. This proved the importance of having a first-flush concept on the rainwater harvesting system. The treatment process using *Moringa oleifera* as disinfectant improved the quality of the rainwater in terms of removing some of the microbial component. An amount of 2.75 mg/ml of seeds dissolved and mixed with distilled water at 85 rpm for 21 minutes is the optimum parameter to prepare the disinfectant. Harvested rainwater in KOE-IIUM still needs another type of treatment to improve and utilize the water for more than cleaning and flushing.

From the study conducted, there are a few recommendations that could be made for further study. First, analyze and compare the quality of the rainwater harvested from roof catchment and harvested directly from the sky by prepare an open tank to collect the rainwater. Furthermore, install a first-flush device along the downpipe so that the quality of the rainwater store in the tank is improved.

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