Rainwater Harvesting Design Uncertainty Using Fuzzy Logic

Supiah Bt Shamsudin, Azmi Ab Rahman, Zaiton Bt Haron, Salisu Danazumi, Siti Hawa Bt Jalil, Mohd Azizi B Zakaria

Abstract— ***One of the biggest environmental challenges that face Malaysia today is the scarcity of water. The increased need of water resources caused by population growth and rapid industrialization has created the need to manage water resources more efficiently and effectively. Many methods are developed to increase the source of water supply; one alternative source is rainwater harvesting. Rainfall harvesting from catchments has not received large attention in Malaysia. This method is one of the proactive action can be taken to avoid shortage of water resources in the future. The analysis results showed the maximum and minimum flow rate according to return year obtained using Fuzzy membership functions establishment. Retention times obtained from MATLAB are 7.27 days. Using a Rational method, the relationship between flow rate and intensity is created. The relationship yields an equation that is y = 0.0000317x and R2 = 0.9855. Then, the relationship between coefficient and intensity yields an equation that is y = -0.0031 x + 1.317 and R2 = 0.9238. All assumptions and calculations in this study are based on studies undertaken. In general, the findings can be summarized as good based on the results obtained.***

Index Terms— ***fuzzy membership function, MATLAB, overflow, rainwater harvesting and tank size.***

Abstrak - Cabaran terbesar alam sekitar di Malaysia hadapi hari ini adalah kekurangan air. Keperluan yang meningkat kepada sumber air bersih disebabkan oleh pertumbuhan penduduk dan perindustrian yang pesat telah mewujudkan keperluan untuk pengurusan sumber air yang lebih cekap dan berkesan. Banyak kaedah telah digunakan untuk meningkatkan sumber bekalan air; salah satu alternatif adalah penuaian air hujan. Namun, penuaian hujan dari kawasan tadahan tidak mendapat perhatian yang besar di Malaysia. Kaedah ini adalah salah satu tindakan proaktif yang boleh diambil untuk mengelakkan kekurangan sumber air pada masa akan datang. Keputusan analisa menunjukkan kadar aliran maksimum dan minimum mengikut tahun kembali diperolehi dari pembentukan fungsi keahlian fuzzy. Masa tahanan yang diperolehi dari MATLAB adalah 7.27 hari. Menggunakan kaedah Rasional, hubungan antara kadar aliran dan intensiti dicipta. Hubungan tersebut menghasilkan satu persamaan iaitu y = 0.0000317x dan R2 = 0.9855. Kemudian, hubungan antara pekali dan intensiti menghasilkan satu persamaan bahawa y = -0.0031 x + 1.317 dan R2 = 0.9238. Semua andaian dan pengiraan dalam kajian ini adalah berdasarkan kepada kajian yang dijalankan. Secara amnya, dapatan kajian boleh dirumuskan sebagai baik berasaskan kepada keputusan yang diperolehi.

Kata kunci— ***fungsi keahlian fuzzy, limpahan, MATLAB, saiz tangki dan penuaian air hujan.***

Manuscript received on May, 2013.

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I. INTRODUCTION

The rapid socio economic development in this country poses pressure to water supply and irrigation in the country. Furthermore, the limited water releases from the dam resulted in a reduction of normal production. Therefore, another alternative is to reduce the water needs of the country. Rainwater harvesting is one way to mitigating the problem of reduction water resources in addition to addressing the flooding problem that occurs in Malaysia.

Water harvesting systems provide flexible solutions that can effectively meet the needs of new and existing, as well as of small and large sites, using a water harvesting system is an on going effort that can be developed over time. The greater attractions of a rainwater harvesting system are low cost, accessibility and easy maintenance at the household level [1].

Background Problems

In Malaysia, population has increased and the demand for clean water has increased too. To cater for the demand, water treatment plants and dams have to be constructed to meet the needs of the people. As the demand increases and eventually exceed the water supply, the situation will create problem to the country.

The people attitude also plays an important part towards creating a sustainable living. There are campaigns about how important the water is, but people still waste the water. If the water is not wasted, it not only will save the people's water bill but will also reduce the stress on water demands as well as possess sufficient reserves for emergency uses such as droughts and dry spells.

Since clean potable treated water is important, it is seen in this context as a waste for it to be used for flushing of toilets and for watering plants. Furthermore, rainwater can be used as a substitute for flushing and other purpose. Besides that, flash floods can be minimized as some proportion of the rainfall is retained and thus reducing the surface runoff.

A. Study Objective

The objectives of this study are:

1) To determine the optimum size of rainwater harvesting tank.
2) To determine the most likely range of flow rate using Fuzzy Membership Function.
3) To estimate optimum time to detain water to prevent overflows using Fuzzy Logic MATLAB.

B. Scope of Study

To accomplish the objective specified above, it is necessary to obtain pattern of rainfall in the study area which is M41, UTM Johor Bahru, Johor.

Then, the sample roof area was calculated and the potential rainwater harvesting volume is estimated based on the total roof area, the rainfall intensity and the runoff coefficient. After that, the rainwater harvesting volume is compared with water consumption demand. Lastly, MATLAB software was applied to obtain the optimum time to detain water to prevent overflow. The optimum time or detention time depends on flow rate and volume of the tank.

II. LITERATURE REVIEW

Access to water supply is fundamental to life and health. By extension, it is a prerequisite to realizing other basic human rights. The vital importance of water for development is reflected in one of the Millennium Development Goals (MDGs) which requires halving the proportion of people without access to safe drinking water and adequate sanitation by 2015. Innovative approach towards water supply is needed to meet this huge challenge [2].

In 1998, Malaysia faces a serious water crisis because of the drought from climate changes (El Nino Phenomena). Due to this, Lembah Klang is one of the top critical places having the water crisis. The State Water Board has to ratio all the water supply to make sure the entire users get enough water at that time. Government listed some of the efforts that can be employed for water storage and rainwater harvesting system is one part of it. However, the implementation of this system is not moving further because of lack awareness among the users [3].

Malaysia's is working hard to find alternative water supply to cope with the rising demand in water. Draught in 1998 should be a good wake up call for the decision makers and the community. Straight after the incident, the Ministry of Housing and Local Government has introduced a guideline on rainwater harvesting (1999) but it generally passed by without notice. As time passed by, the incident was forgotten until March 27, 2006, the Prime Minister announced that rainwater harvesting would be made mandatory to large buildings (2007). However, up till now very few government buildings have used rainwater harvesting as an alternative source of water supply [4].

A rainwater harvesting option is a very suitable method for providing water to the local residents in Malaysia, for the following two reasons. First, Malaysia has good meteorology and geographical characteristic for rainwater harvesting. The average annual rainfall is 3000mm and it tends to be distributed evenly throughout the year, without distinct differences between the dry and wet seasons. Second, the drought experienced during the 2006 supported the idea of promoting rainwater as an alternative water supply option.

The basic rainwater harvesting system consists of 3 major parts which is the catchment area, the conveyance system and the storage tanks. The material used for these components will influence the efficiencies as well as the quality of the rainwater collected. Catchment area is the surface area from which rainwater can be collected. Usually, this comprises the roof over the house, and any associated covered portions of the dwelling including sheds, factory roofs etc. that is situated above ground level [5]. Although rainwater can be harvested from many surfaces, rooftop harvesting systems are most commonly used as the quality of harvested rainwater is usually clean following proper installation and maintenance.

Conveyance systems are required to transfer the rainwater collected on the rooftops to the storage tanks. This is usually accomplished by making connections to one or more down-pipes connected to the rooftop gutters. The best pipes used for conveying rainwater should be made from plastic such as PVC or other inert substance that can keep the pH of rain water and will not cause corrosion and mobilization of metals in metal pipes.

Storage tanks for collected rainwater may be located either above or below the ground. They may be constructed as part of the building or may be built as a separate unit located some distance away from the building. The design considerations vary according to the type of tank and other factors.

III. METHODOLOGY

For the preliminary research, the Basic Membership Function was studied and its function understood. After that Fuzzy logic parameters, and data collection process can began. The data that need to be obtained are size of tank, peak discharge and optimum detention time.

The average annual rainfall, area of catchment and runoff coefficient serve as basic requirement for the designed size of the tank based on the harvested rainwater. The rainfall intensity data was obtained by calculation. The area of catchment and runoff coefficient were used to obtain the peak discharge, Qp. Then, tank size is designed based on water demand from the study area. After that, Basic Fuzzy Membership was applied to obtain the retention time.

A. Rainfall intensity, i

The rainfall intensity value is the rainfall rate (mm/hr) that falls during storm event. The Rational Method is applied in the calculation of the rainfall intensity for the rainwater harvesting system, the whole catchment is assumed uniform. The value can be obtained from Intensity Duration Frequency (IDF) equations. Figure 1 (Fig. 1:) shows general procedure for the estimation of peak flow using Rational Method.

The Polynomial approximation applied;

$$\ln I = a + b(\ln t_c) + c(\ln t_c)^2 + d(\ln t_c)^3$$

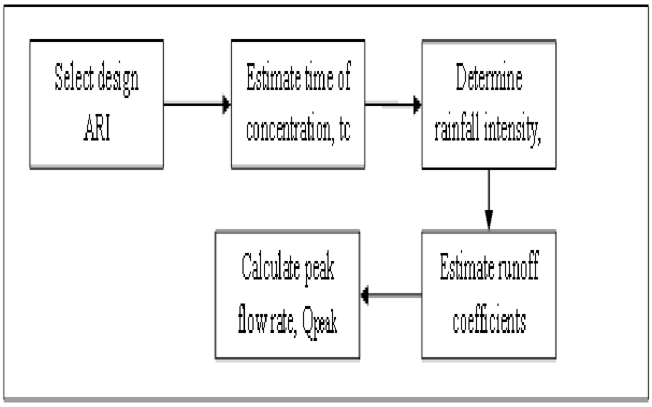

Fig. 1: General procedure for estimate peak flow

ISSN: 2231-2307, Volume-3, Issue-2, May 2013

B. Catchment Area

The dimension in metre of the roof block M41 is shown in Fig. 2. The perimeter of the roof is 97.03m while the area of roof is 372.8m². All the rooftop has the potential to harvest the rainwater but in this study, only the middle area was determined as catchment which is 142.6m2.

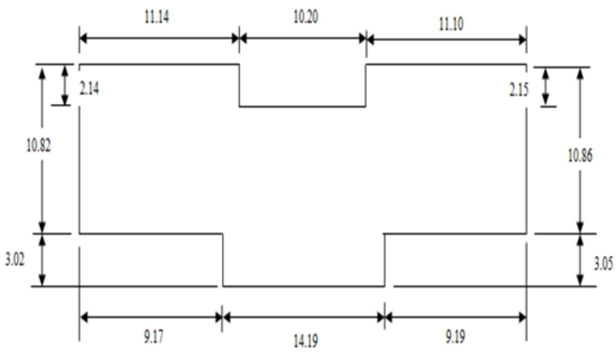

Fig. 2: The dimension of the rooftop

C. Roof Area Random Number

Random number is obtained from the using of Microsoft Excel random generator. Random number should be performed to find the average value which is similar to the roof area used in this study. Fig. 3 shows the value of the random number that obtained from the Microsoft Excel random generator.

	A	B	C	D	E	F	G
1							
2		Random Area					
3		56.69					
4		132.25					
5		19.96					
6		214.00					
7		89.30					
8		177.11					
9		129.60					
10		230.69					
11		160.87					
12		214.03					
13							
14	Average Area	142.45					
15							

Fig. 3: Roof Area

D. Basic Fuzzy Membership Function

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. The input space is sometimes referred to as the universe of discourse. Raw data such as Qpeak was obtained and used in the creating of a histogram. Frequency analyzed was carried out before the histogram is created. The objective of frequency analysis is to find out how often a hydrologic event occurs in a given period. The formula to give the peak flow discharge (Qp) is shown below.

$$Qp = C \times i \times A$$

Where; C = Runoff Coefficient (depend on catchment characteristic)

i = Intensity of rainfall in time, Tc (time of concentration)

A = Area of catchment

E. Fuzzy Logic Toolbox

Fuzzy Logic Toolbox graphical user interface (GUI) is used to build a Fuzzy Inference System (FIS) for the retention time estimation. Fig.4 shows the fuzzy inference system image. There are following GUI tools to build, edit and view fuzzy inference system.

1) Fuzzy Inference System (FIS) Editor is to handle the high level issues for the system. Fuzzy Logic Toolbox does not limit the number of inputs. However, the number of inputs may be limited by the available memory.
2) Membership Function Editor is to define the shapes of all the membership function associated with each variable.
3) Rule Editor is to edit the list of rules that defines the behaviour of the system
4) Rule Viewer is to view the fuzzy inference diagram. This viewer shows the individual membership function shapes that influence the results.
5) Surface Viewer is to view the dependency of one of the outputs on any one or two of the inputs. It generates and plots an output surface map for the system.

Fig. 4: Fuzzy inference system image

Retention time

The definition of retention time most familiar to designers is given by the storage volume divided by the flow rate at which flow rate either enters or leaves the storage facilities [6]. In design the rainwater harvesting tank, retention time is one of the aspect is important. Based on propose rainwater harvesting tank design, the retention time was estimated using Fuzzy Logic Toolbox.

IV. RESULT

A. Basic Fuzzy Membership Function for 2 Years Return period

A return period of 2 years is choosing in this calculation. Table 1 shows a flow rate data from the analysis of 2 years return period (Tr2). The minimum value of flow rate is 0.0005 and maximum is 0.0076.

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Table 1: Flow Rate Data for Tr 2

The data as obtained from the above table are grouped according to the range specified by the analyst. The determination of this range depends on the range of convenience and did not influence the determination of the final value. To obtain a more accurate final value, the smaller range is required. Table 2 shows a relative frequency for 2 year return period.
Relative frequency is obtained when the frequency is divided by the amount of data. Further, the histogram is created from the relative frequency that was obtained.

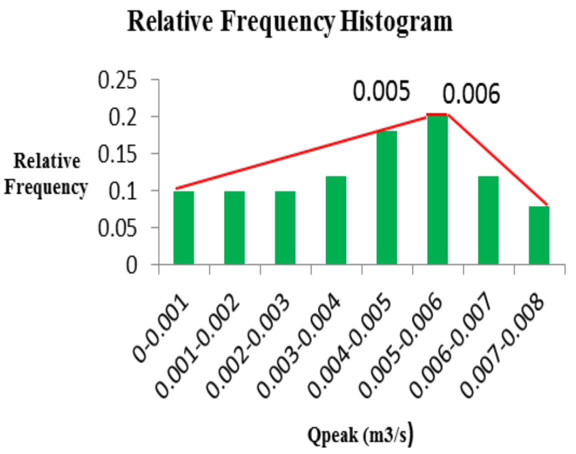

Fig. 5: Relative Frequency Histogram for Tr 2

The data inline will be used in programming before other generic process is done. Fuzzy membership is equal to the relative frequency. Fig.5 shows the most likely range values obtained, namely 0.005-0.006.

B. Data Analysis

Data analysis was to examine the relationships between the selected data. These data will produce results either directly or inversely proportional and will produce an equation.

***Flow rate, Q and intensity,* i**

The return period for rainfall intensity is used to develop the relationship with flow rate. Using area 142.6m2, runoff coefficient of 0.8 and return period of rainfall intensity, the graph is created. The rational formula described below is used for this purpose.

$$Q = CiA \quad (1)$$

The coefficient and roof area is constant in this calculation and intensity is variable. So, (1) can be written in the following

$$Q = Ki \quad (2)$$

Where K is constant and its value can be determined from the graphical relationship between Q and i.

Fig.6 shows that the intensity and flow rate is directly proportional. Relationship between these parameters yields an equation that is y = 0.0000317x and R2 = 0.9855.

Table 2: Frequency Table for Tr 2

Range	0-0.001	0.001-0.002	0.002-0.003	0.003-0.004	0.004-0.005	0.005-0.006	0.006-0.007	0.007-0.008
Frequency	5	5	5	6	9	10	6	4
Rel. Fre	0.1	0.1	0.1	0.12	0.18	0.2	0.12	0.08

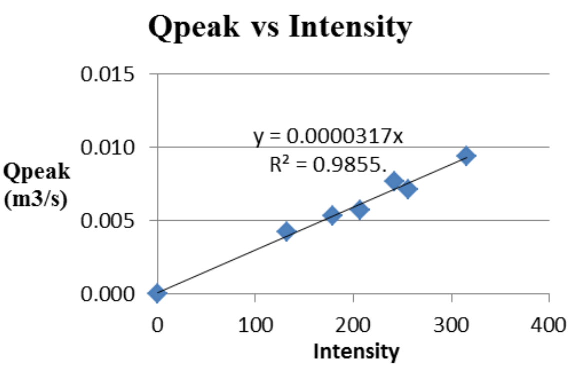

Fig. 6: Flow Rate versus Intensity Graph

From the relationship, the value can described as

$$Q = 0.0000317i \quad (3)$$

From (3), it can be concluded that the value of K is equal to 0.0000317 and the value of K can be described as

$$K = CA$$

Runoff Coefficient, C and Rainfall intensity, i

The rainfall intensity is used to obtain the relationship with runoff coefficient. Using return period intensity, flow rate, Qavg and random number area, the graph is created. The flow rate and roof area is constant in this calculation and intensity is variable. So,(1) can be written in the following

$$C = K/A \quad (4)$$

Where K is constant and its value can be determined from the graphical relationship between C and i.
Fig.7 shows that the runoff coefficient and rainfall intensity are inversely proportional. Relationship between these parameters yields an equation that is y = -0.0031 x + 1.317 and R2 = 0.9238.

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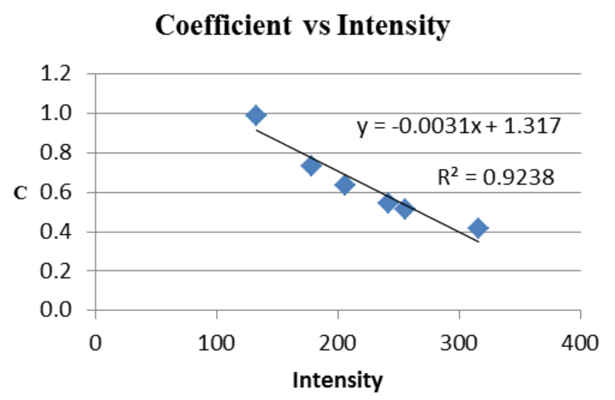

Fig.7: Coefficient versus Intensity

From the relationship, the value can described as

$$C = -0.0031i + 1.317 \quad (5)$$

From (5), it can be concluded that the value of K is equal to -0.0031 and the value of K can be described as:

$$K = Q/i$$

Fuzzy Logic Approach for Time Analysis Status using MATLAB

In this section, Fuzzy Logic Toolbox graphical user interface (GUI) tool was used to build a Fuzzy Inferences System (FIS) for the rainwater harvesting timing. Although MATLAB can build a FIS by working directly from the command line, it is much easier to build a system graphically. Five primary GUI tools for building, editing and observing fuzzy inference systems in the box are Fuzzy Inference System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer and Surface Viewer.

As can be seen below, Fig. 8 is FIS editor in RWH variable, Fig. 9 is Membership function editor for flow rate, Fig. 10 is Rule editor in RWH and Fig.11 is Rule viewer in RWH. In the diagram, the time analysis status is influenced by two variables. Membership function is created for each variable in membership function editor in MATLAB. For flow rate, the range was set up as [0 0.1] and volume range is [0 400]. While, for time was set up as [0 30].

In this case, time analysis was defined by entering the value of flow rate and volume as [0.0057 2.5] in input field. The output was displayed as 7.27 and it shows that the retention time in the storage tank is medium. The result in surface viewer was shown in Fig.12.

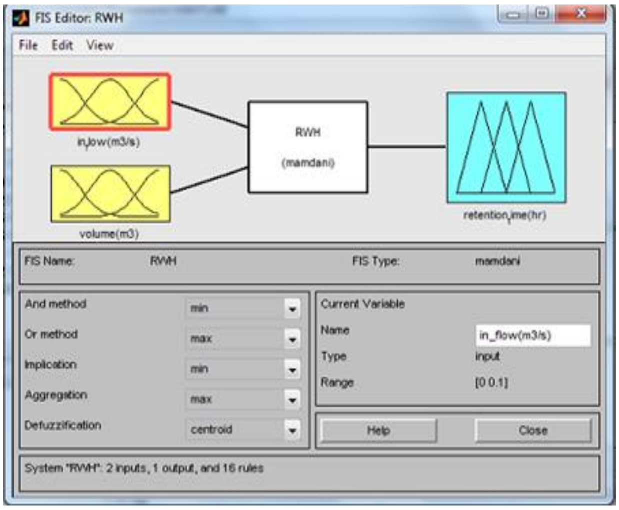

Fig. 8: FIS editor in RWH variable

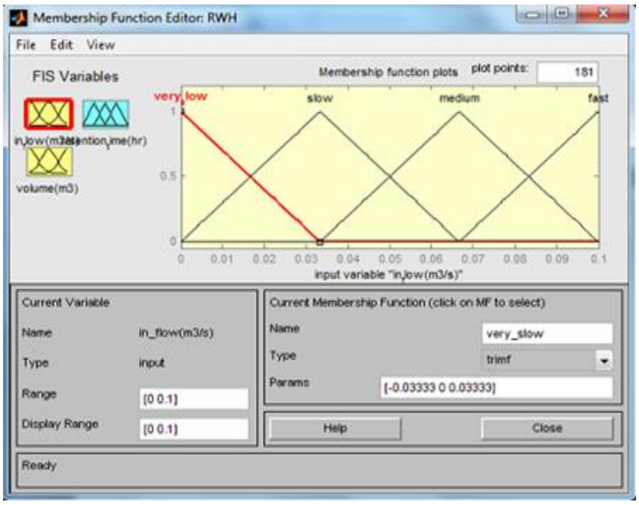

Fig. 9: Membership function editor for flow rate

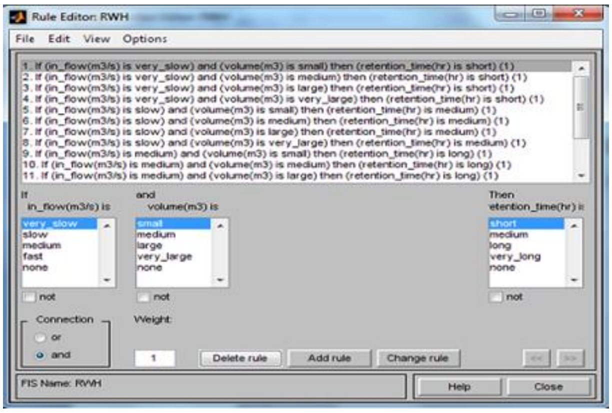

Fig. 10: Rule editor in RWH

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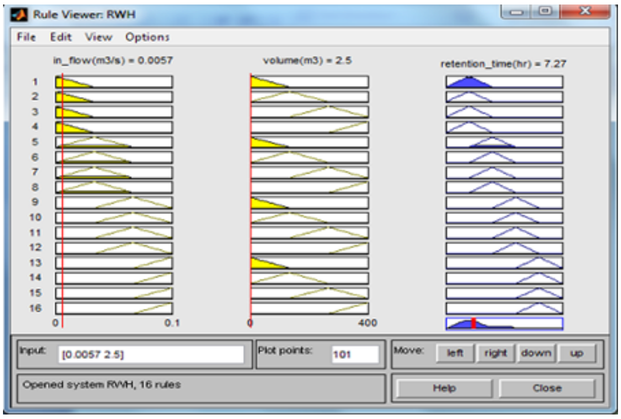

Fig. 11: Rule viewer in RWH

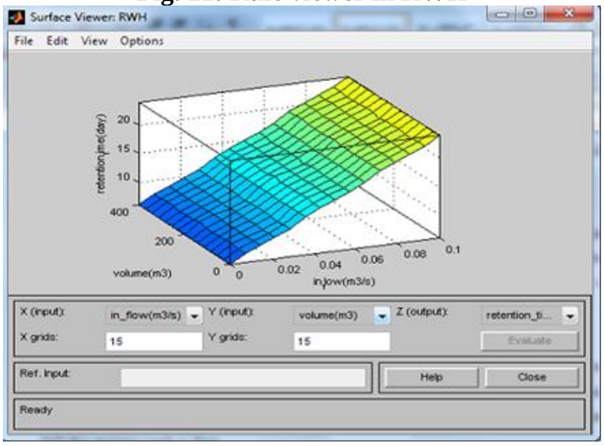

Fig. 12: Surface Viewer

V. CONCLUSION

Rainwater harvesting practices in campus for non-potable water usage such as flushing and irrigation will have many benefits that can be seen economically and environmentally. Water bills can be saved and flash floods phenomenon can be overcome. By employing rainwater harvesting, it can seen as one of the alternative to becoming environmental friendly surroundings and to minimize the energy usage.

The proposal to expand the use of rainwater harvesting systems has to be applied and practiced. Before installing rainwater harvesting system in whole campus, M41 which is the building for Occupational Safety and Health (OSHE) office need to be further investigated to determine the efficiency of the system. Then, the system can be applied to the whole campus.

In MATLAB, estimation of retention time was done using the Fuzzy Logic Toolbox. This system consists of two inputs and one output. Flow rate was represented in the unit of m^3/s and volume in the unit of m^3. The retention time has been produce from these inputs. Result has shown that retention time is medium. At this stage, it shows that the rainwater harvesting will not be retained too long in tank.

ACKNOWLEDGMENT

All the authors are grateful for the provision of research grant VOT 79394 from the Ministry of Science, Technology and Innovation (MOSTI) Malaysia. We appreciate the help and assistance from the technical teams of UTM Hydraulics and Hydrology Laboratory. We are also very thankful to everyone involved directly or indirectly.

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