Checking the Adequacy of Rainwater Harvesting System for Housing and Landscaping

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ABSTRACT

Rainwater harvesting is the collection of water volume from raindrops. Rainwater harvesting has been the main source of water supply for potable and non-potable uses in the old days because the water conveyance systems were not used for water distribution and the method used for rainwater harvesting was simple and primary (rainwater was mostly collected from roofs and some was collected directly from the sky). Usage of the collected water volume from rainwater harvesting was direct and without any treatment. Presently, the water supply systems have improved but the demand is increasing due to the population growth, and development. Rainwater can be used for potable and non-potable uses. The potable uses include drinking, cooking, bathing and washing. Usually, the rainwater used for this purpose must be treated to remove the contaminants. Non-potable uses include flushing toilets, watering garden and washing floor where treatment of rainwater is not required for these purposes. The volume of rainwater collected from rainwater harvesting system varies from place to place and depends on weather. In the present study, a rainwater harvesting system was installed in the Faculty of Engineering, University Putra Malaysia, Malaysia. The system is composed of the catchment (roof), gutter, pipe, steel tank and treatment unit. From 20 different rain events, the collected volume of the rainwater from different events ranges between 0.17 m^3 and 2 m^3. The daily water consumption is monitored for one month and compared with the collected rainwater volume. The volume of collected rainwater is found to be adequate to meet the non-potable uses. In a tropical country like Malaysia it is easy to collect 2 m^3 in a single rain while 10 m^3 is collected annually in Zambia, Africa from a roof of almost of the same size. The rainwater harvesting can be used for landscaping and the computation made to determine the volumes of yield and consumption shows that rainwater is also adequate to meet the requirement for landscaping in rainy months.

Keywords: Rainwater, adequacy, housing, non-potable uses, landscaping

1. INTRODUCTION

World's population has been constantly increasing and so has the water demand. However, supplies from water resources are limited and estimated to be 2% from the total available water in nature. The population growth has direct influence on the water supply demand rates. For example, worldwide water demand has increased six folds between 1990 and 1995 while the population has only doubled and the demand of the agricultural sector is almost 70% of the total demand (Apan 2000). The rate of the growth in the urban area is about four times that of the rural areas. Based on this fact, the rainwater harvesting in housing areas with abundant rain can help to overcome the water shortage and be in line with sustainability development. With the development and growth of urban populations, the paved and roof area will increase and this situation is ideal for implementing rainwater harvesting techniques. Rainwater harvesting had been the main source of water supply for potable and non-potable uses in the old days because the water supply systems were not developed yet. The method of harvesting rainwater at that time was simple and primary. Usage of the collected water volume from rainwater harvesting was direct and without any treatment. The rainwater was mostly collected from roofs and some was collected directly. Based on the size of the catchment, rainwater harvesting systems can be divided into medium and small. The medium size is a system which collects rainwater from catchment areas in educational institutions, airports, army camps, and others. Small systems collect rainwater from the roof of houses. Water can also be collected from open areas and stored in a depression of land or basins.

The storage from rainwater harvesting system can be used for potable and non-potable uses. It is preferable to integrate the rainwater harvesting systems with the existing conventional water supply systems. This will help to meet the increasing demand of water supply and contribute in the sustainability of the water supply. Many countries around the world are still promoting the usage of harvested rainwater for potable and non-potable uses. Examples of these countries are USA, Germany, Australia, China, and Japan. The volume of rainwater collected is different from place to place. For example, based on a pilot project in Zambia, Africa, a volume of 10 m^3 of rainwater was collected annually (Handia 2002). On the other hand, a volume of 2m^3 of rainwater was colleted in the system used in the present study.

2. Rainwater Harvesting System for Housing

Although water supply systems for housing have been improved, the demand is increasing due to population growth and development. The prolonged dry period due to global weather change can be considered as another factor affecting water supply for housing areas. This leads to water shortages in many countries around the world. Rainwater can be used for potable and non-potable uses. The potable uses include drinking, cooking, bathing and washing dishes. Usually the rainwater used for this purpose must be treated to remove the contaminants. Non-potable uses include flushing toilets, watering garden and washing floor and treatment of rainwater is not required for this purpose. Ideal domestic rainwater-harvesting systems generally are composed of six basic components and these components are the roof (catchment), gutters and down pipes, primary screening and first flush diverters, storage tanks, the pipes, and water treatment unit (TWDB 1997). Most of the rainwater harvesting systems around the world is composed of the roof, gutter, down pipes, and collecting tank. Figure 1 shows the various components of a rainwater harvesting system used in housing. It is important to estimate the volume of rainwater harvesting and also to know the water consumption. The domestic water consumption is different from country to country in the world. Texas National Resource Conservation Commission, TNRCC proposed a formula to compute the volume of rainwater for Austin city, Texas, USA (TNRCC 2003). The formula was modified by Mohammed et al. (2004) to fit the Malaysian condition. The modified formula is presented below:

$$V = 0.00685xAxE \qquad (1)$$

where

V is the average daily volume in m^3, A is the roof area in m^2, and E is the system collection efficiency. Equation (1) is applied to compute the volume of rainwater collected from a roof of the concrete laboratory, Civil Engineering Department, Faculty of Engineering, Universiti Putra Malaysia, Selangor, Malaysia. Equation (1) is based on an average annual rainfall depth of 2500 mm and system collection efficiency of 75% as given by TNRCC (2003). The size of the roof catchment is 150 m^2 and the computed volume is found to be 0.8 m^3. However, the rational formula and the guidelines of Urban Stormwater Management Manual for Malaysia can be used to compute the volume of the rainwater from a roof catchment (DID 2000). According to the guidelines of the Ministry of Housing, Malaysia, an average of 5 persons normally occupy a house in the state of Selangor (Ministry of Housing, Malaysia 1999). Based on recommendations by TNRCC (2003), the estimated daily water consumption for a house in the state of Selangor was found to be 1.25 m^3. Shaaban et al. (2002) found the average water use for facilities using rainwater in Kuala Lumpur, Malaysia is 0.445 m^3. This volume represents the rainwater consumption for washing, toilet flushing, and general cleaning.

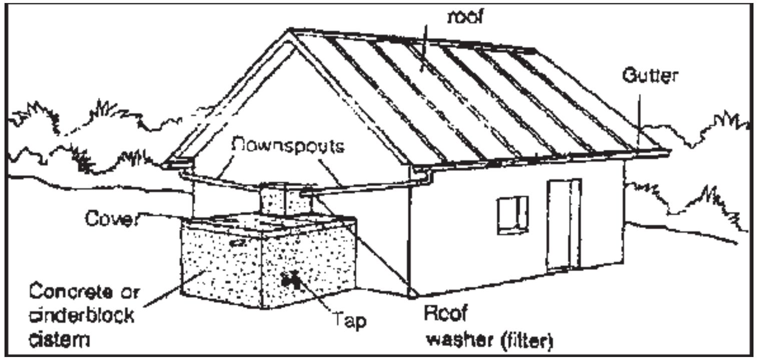


Figure 1. Components of rainwater harvesting system for a house (Source: IETC 1995)

However, the rainwater was not subjected to any treatment before usage. Once rain comes in contact with a roof or collection surface, it can wash many types of bacteria, moulds, algae, protozoa and other contaminants into the cistern or storage tank. Indeed, some samples of harvested rainwater have shown detectable levels of these contaminants. Health concerns related to bacteria, such as salmonella, e-coli and legionella, and other contaminants, such as pesticides, lead, and arsenic, are the primary criteria for drinking water quality analysis. For example, if the rainwater is intended for use inside the household (potable uses) such as drinking, cooking and showering then appropriate filtration and disinfection practices should be employed. But if the rainwater is intended for non-potable uses including toilet flushing, floor cleaning, car washing, and for landscape irrigation, where the presence of contaminants may not be of major concern, thus treatment requirements can be less stringent or not required at all. Depending on where the system is located, the quality of rainwater itself can vary, reflecting exposure to air pollution caused by industries such as cement kilns, gravel quarries, crop dusting, and a high concentration of automobile emissions. In most industrialized urban areas, the atmosphere has often been polluted to such a degree that the rainwater itself is considered unsafe to drink (Thomas and Greene, 1993). Heavy metals such as lead are potential hazards especially in areas of high traffic density or in the vicinity of heavy industries (Thomas and Greene, 1993 and Yaziz, et al., 1989).

3. Research Method

In this study, the rainwater volume collected at the tank of rainwater harvesting system is monitored for more than 20 rainy days. The rainwater harvesting system is installed at the Faculty of Engineering, Universiti Putra Malaysia, UPM. The maximum volume of rainwater collected in the tank is 2 m^3. The water consumption by students for flushing toilet in one of the washroom is monitored too. A flow meter to measure the volume of water consumed is installed in the washroom used by students. The maximum volume of water per day consumed daily by students using the monitored washroom was found to be 1.82 m^3. Samples are collected directly from the down pipe of the rainwater harvesting system in order to monitor the quality of rainwater. The samples are taken to the public health laboratory, Department of Civil Engineering, UPM to be analysed. The results show that the rainwater is slightly acidic and contain small concentration of lead. In Malaysia, rainwater harvesting is not widely used and many Government agencies such as Ministry of Housing and Department of Irrigation and Drainages (DID) are working to produce guidelines for installation of rainwater harvesting system for housing and buildings. In this study, the installation of the rainwater harvesting system is aimed to collect real data on rainwater harvesting system used for housing. This is because it is not easy to get data on such system.

4. Determination of System Adequacy for Housing

A rainwater harvesting system has been installed at the Faculty of Engineering, Universiti Putra Malaysia and the main objectives from the system installation are to determine the optimum tank size for the system and also to study the quality of the collected rainwater. The components of the system are roof catchment (150 m^2), first flush unit, steel tank and PVC pipes (150 mm diameter). In the present study, special emphasis will be given for volume of collected water for different rain events. Table 1 shows various parameters in rainwater samples collected from the down pipe of the system. Most of the parameters are within the acceptable range but some are higher than the acceptable range especially the heavy metals. The collected volumes of rainwater in the tank of the system fluctuated with rainfalls. Figure 2 shows variation of collected rainwater volumes in the tank for 20 different rain events. It was observed that the maximum volume of the collected rainwater was 2 m^3 while the minimum volume was 0.17 m^3. This can provide indication about the size of the tank to be used with the rainwater harvesting system for a house. On the other hand, the consumption of water from three washrooms (toilets) located at the faculty of Engineering, Universiti Putra Malaysia was monitored using flow meters. The maximum water consumption was found to be 1.82 m^3 per day. The storage of the rainwater in the tank is compared to the consumption of water for non-potable uses (water consumption in the washrooms) and it was found that the storage was higher than the consumption. However, it was found that there were times when the storage was either equal or lower than the consumption as shown in Figure 3.

5. Rainwater Harvesting For Landscaping

Rainwater can be captured, diverted, and stored for the purpose of using it for plant irrigation of landscapes. The landscapes can be divided into large-scale areas such as parks, schools, commercial sites, parking lots, and apartment complexes. Also it can be suitable for small-scale residential landscapes (Figure 4). A rainwater harvesting system for watering purposes of landscapes has three components, namely the supply source (the catchment), the demand (landscape water requirement), and the conveyance system which help to convey rainwater to the plants (Waterfall, 1998). Storage can be added to the system if necessary. The volume of rainwater planned to be used for landscapes mainly depends on rainfall intensity, rainfall duration, frequency of the rainfall, and degree of saturation for catchment ground surface and its nature. Ground surfaces of catchments are generally categorized to almost fully impervious or partially impervious or almost fully pervious. More rainwater can be captured (used immediately or stored) from a catchment with fully impervious ground surface compared with a catchment of pervious ground surface. For landscapes, the selected type of plant, age, size, and spacing between successive plants are factors which contribute to the success of using rainwater in landscape areas. For example, in arid regions, where the rainfall intensity is low, low plant density must be used for the landscaping and plants used must be from species which require less water. This will reduce overall water need which fit the climatic condition. Native plants are well adapted to seasonal, short-lived water supplies, and most desert-adapted plants can tolerate drought, making them good choices for landscape planting and contribute in the success of using rainwater for landscapes. Rainwater volume required for landscapes can be determined by having a good recorded date for both collected volume (yield) and consumption. Water saving due to employing rainwater harvesting system can be determined using the following formula:

$$\textit{Annual Water Saving} = V_1 - V_2 \qquad (2)$$

where V_1 is the volume of water before construction of rainwater harvesting system, and V_2 is volume of water after construction of rainwater harvesting system.

Using rainwater for landscapes can help to reduce water supply for municipal purposes. There are many advantages of using rainwater for landscapes such as to reduce groundwater exploitation, to reduce flooding, to control erosion and to improve water quality by holding storm runoff on site (on site detention), and cost reduction. Limitations of water harvesting are few and are easily met by good planning and design. Water harvesting systems for landscaping ranges from simple to complex. A simple system usually consists of a catchment area where the rainwater can be harvested and a water conveyance system that transfers rainwater to the plants via gravity. A good example of a simple system is water dripping from the edge of the roof to a planted area or to a diversion channel located directly below the roof gutter and water moves by gravity to the location of the plants. Water conveyance system connects the catchment area with the irrigated area and it can be very simple or very sophisticated. For example, gutters and downspouts can direct rainwater to a garden or plants of a landscape if sidewalks are gently sloped. Channels, ditches, and swales can be utilized as water conveyance. Curb cutouts can channel street or parking lot water to planted areas as shown in Figure 5. The pervious blocks can be bounded by grass in order to hold water for irrigating plants used for the landscaping (Figure 6). Complex rainwater harvesting system is suitable when gravity flow is not possible and rainwater can be stored in natural depression, excavated pit or a tank and a pump must be used to supply the rainwater for irrigation. Storage allows full utilization of excess rainfall by making water available later when it is needed. Complex rainwater harvesting system is costly and can be used for larger facilities and requires professional assistance in its design and construction. A self-sufficient rainwater harvesting system must be of a complex type which can provide enough water in an average year where the surplus volumes of rainwater can be stored in a tank and then be used between rainfall events or at dry periods. In complex systems, the cost of storage is greater than the cost of public water supply but it promotes water conservation habit in the society. Water harvesting cannot provide a completely reliable source of irrigation water because it is dependent on the weather, and weather is unpredictable.

Table 1. Tested Parameters in Rainwater Samples

Parameter	Unit	Untreated	Malaysian Standard
pH		5.71	6.5 - 9
Turbidity	N.T.U	3.97	5
BOD_5	mg/L	1.20	3
Total Suspended Solids	mg/L	10	50
Total Dissolved Solids	mg/L	12	50
E.coli	CFU/100m	1	0
Lead	mg/L	0.006	<0.003

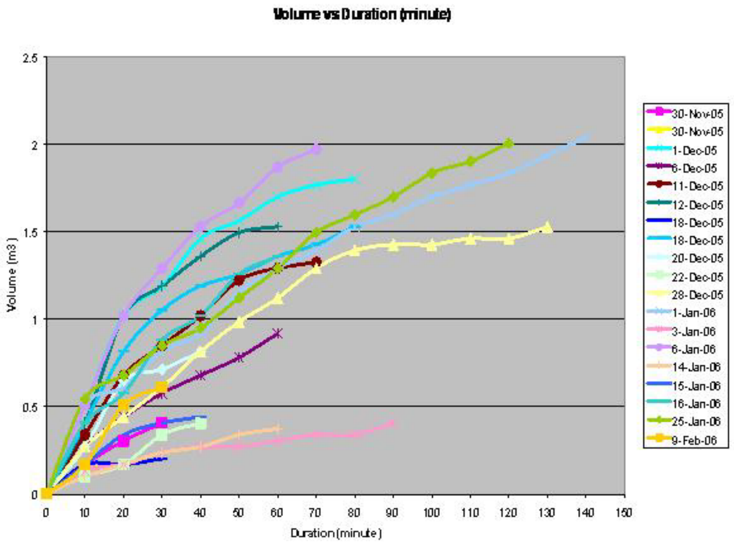


Figure 2. Variation of the collected volume of rainwater with time.

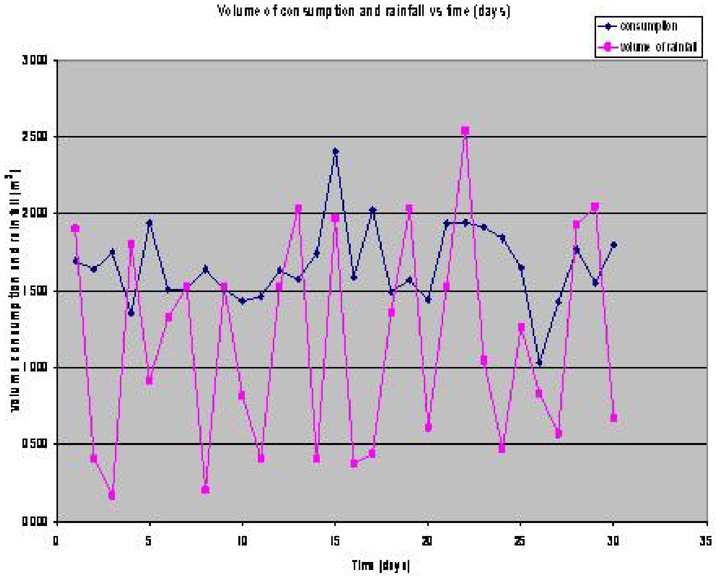
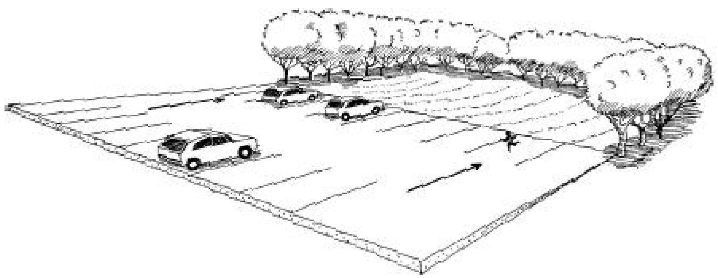


Figure 3. Comparison between the storage of rainwater and water demand for a non-potable use (such as wash room).



a.Rainwater harvesting for irrigating plants in a car park.

b. Rainwater harvesting for irrigating plants of a house landscape.

Figure 4. Rainwater harvesting for landscaping (Source: Waterfall, 1998).

Drip irrigation systems can be designed to distribute rainwater to the plants from a storage tank using pumping. Before the rainwater is stored it should be filtered to remove large particles and debris. The degree of filtration is dependent on the size of the distribution pipes and the size of emitters but for drip irrigation systems, it requires fine filter. Inspection and maintenance of a rainwater harvesting system before each rainy season and ideally after every rain event can keep the system operating at optimum performance (Waterfall, 1998). To determine the amount of water available from storage of rainwater harvesting system and also the supplement volume needed, computation of monthly supply or rainfall harvest potential and the monthly demand or plant water requirement for a period of one year can be done by applying the Rational Method.

$$S = A \times R \times C \qquad (3)$$

where S is rainwater volume per month, A is catchment area, C is runoff coefficient, and R is the monthly rainwater depth.

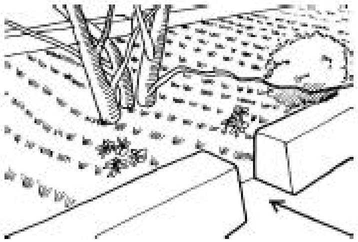


Figure 5. Rainwater for landscaping from curb cut (Source: Waterfall, 1998).

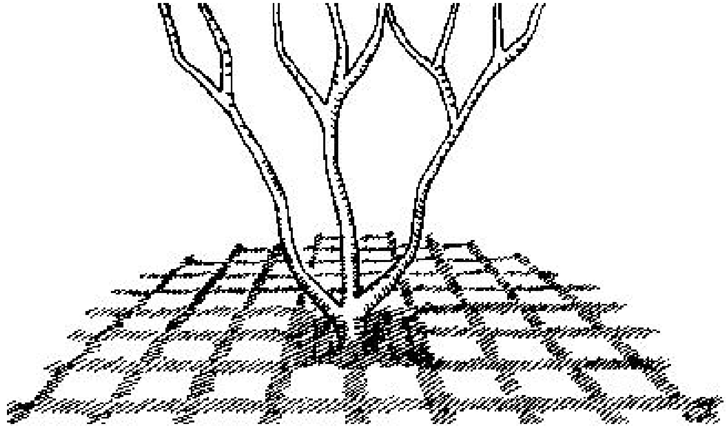


Figure 6. Pervious paving block with grass (Source: Waterfall, 1998).

Table 2 shows typical values of runoff coefficient. Although in reality the amount of water available fluctuates on a daily basis, for simplicity the computation can be done on a monthly basis. The volume of water required by the plants (demand) is computed based on monthly evapotranspiration data using the following equation:

$$D = ET_o \times \beta \times A \qquad (4)$$

where D is monthly water volume required for landscaping, (ET_o) is monthly evapotranspiration, β is the plant factor, and A is the irrigated area.

Using plants of similar water requirements will simplify the system and make the amount of water needed to maintain those plants easier to compute. Equations (3) and (4) are usually used to compute rainwater volume collected by the rainwater harvesting system and plant demand for both new and established landscapes. The plant factor represents the percent of ET_o that is needed by the plant and it mainly depends on the type of the irrigated plant (high, medium, or low water use) (Waterfall, 1998).

Table 2. Typical Values of Runoff Coefficients (Source: Waterfall 1998)

Type of Surface	High	Low
Roof: Metal, gravel, fiber glass, mineral	0.95	0.90
Paving: Concrete, asphalt	1.00	0.90
Gravel:	0.70	0.25
Soil: Flat, bare Flat, with vegetation	0.75 0.60	0.20 0.10
Lawns: Flat, sandy soil Flat, heavy soil	0.10 0.17	0.05 0.13

7. Example

Rainwater harvesting system utilizing 305 m^2 roof area with a runoff coefficient of 0.9 is used to supply 135 m^2 landscape area with plants of low water use (plant factor is 0.26). The recorded monthly rainfall depths and the plants evapotranspiration are shown in Table 3. Computation is made to determine the collected rainwater volume from the catchment area of 305 m^2 (usually called yield) and water volume required by the plants (evapotranspiration) from a landscape area of 135 m^2. The computation can be used to present the adequacy of the rainwater harvesting system. The mass curve (Figure 7) is used to compare the yield and plant water consumption. The regions in the mass curve where the yield line is below the demand line indicate that demand is greater than supply and municipal water will be required to supplement the storage in order to supply the plants with enough water. During the first year, it is clear that there will be a deficit of harvested rainwater because the year begins with an empty storage container. However, beginning of the second year the rainwater storage has built up and there will be enough harvested rainwater for the plants consumption unless a drought occurs.

Table 3. Hydrological Data for the Landscape Site

Month	Evapotranspiration mm	Rainfall Depth mm
Jan.	60.96	30.48
Feb.	91.44	25.40
Mar.	152.4	22.86
Apr.	213.36	7.62
May	243.84	7.62
Jun	274.32	0.0
Jul	243.84	33.02
Aug	213.36	45.72
Sept.	182.88	25.40
Oct.	152.4	17.80
Nov.	91.44	17.80
Dec.	60.96	35.36

This is attributed to the accumulated volume of rainwater during rainy seasons which is not used up by the plants of landscape area and also due to low rates of evapotranspiration from plants during the rainy months. So, storage of rainwater during rainy months can be saved for dry months. During rainy months, overall storage will increase and yield exceeds demand. Each site presents its own set of yield and demand amounts (Waterfall, 1998). Some water harvesting systems may always provide enough harvested water, some may provide only part of the demand. Usually, yield will fluctuate from year to year depending on the weather and also which month the rainfall occurs. Demand may increase when the weather is hotter than normal and will increase as the plants of the landscape grow and their sizes increase. Demand is also high during the plant establishment period which requires more frequent irrigation for new landscapes. If there is not enough rainwater harvested for watering landscape, the available options are to increase the catchment area, to reduce the amount of landscaped area, to reduce the plant density, to replace the plants with lower water use plants, and to use supplementary water source (Waterfall, 1998).

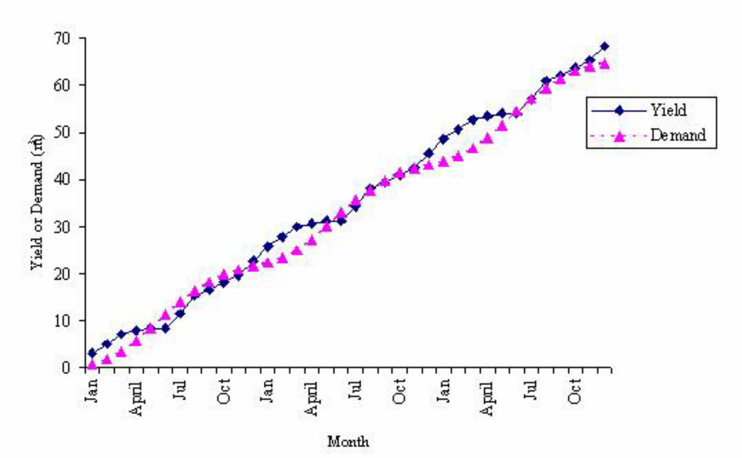


Figure 7. Use of mass curve to determine the possible yield from rainwater harvesting for irrigation.

8. Conclusion

Demand on water supply witness a substantial increase due to development, population increase, and global weather change. Promotion of rainwater harvesting technique for housing and for landscaping can help to reduce the demand on public water supply. Rainwater harvesting systems that will be used in housing schemes can provide water for potable and non-potable uses. The potable uses include drinking, cooking, bathing and washing. Usually the rainwater used for this purpose must be treated to remove the contaminants and generally the main required treatment processes are filtration and disinfection unless the rainwater contains heavy metals, then special treatment is required. Non-potable uses of rainwater harvesting include flushing toilets, watering garden, and washing floors and for such uses treatment is not required. The quantity of the rainwater collected differs from place to place depending on the climate condition. In a tropical country like Malaysia it is easy to collect 2 m^3 (from 150 m^2 roof catchment) in a single rain. The data collected form the rainwater harvesting system installed at the Faculty of Engineering, Universiti Putra Malaysia reveals that volume collected from a single rain can meet the consumption of water for non-potable uses. On the contrary, a volume of 10 m^3 is collected annually in Zambia, Africa from a roof of the same size. This confirms that the collected volume of rainwater is adequate to meet non-potable uses for a household in Malaysia. Rainwater harvesting can also be used for landscaping which contain plants and grass. The yield from a rainwater harvesting system and the demand by the plants can be computed by using Equations (3) and (4). Water supply and rainwater harvesting systems can be integrated to meet the demand for landscapes. During rainy season the rainwater volume is adequate to meet the water volume required for landscaping.

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