STUDY ON POTENTIAL USES OF RAINWATER HARVESTING IN URBAN AREAS

Thamer Ahmed Mohammed, Megat Johari Megat Mohd. Noor, Abdul Halim Ghazali

Department of Civil Engineering
Faculty of Engineering
University Putra Malaysia
43400 UPM Serdang, Selangor, Malaysia
e-mail:thamer@eng.upm.edu.my

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 during these days 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. The available water resources are limited and/or seasonal, which made the experts working in the water sector to search for solutions to the water shortage. Many countries around the world are facing water shortages. Optimization of water usage and the conservation of water as a natural resource can help to overcome water shortage. Rainwater can be used for potable and non-potable uses. The potable uses include drinking, bathing, and cooking 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 and treatment of rainwater is not required for these purposes. The volume of rainwater collected from rainwater harvesting system varying from place to place and depends on weather. In a tropical country like Malaysia it is easy to collect 2 m^3 in a single rain while 10 m^3 was collected annually in Zambia, Africa from a roof of almost of the same size. The main advantages of rainwater harvesting systems are conserving water resources and environment, pollution reduction, help to control flooding, and reduction of impact of weather change. In the present study, a rainwater harvesting system was installed in the Faculty of Engineering, University Putra Malaysia, Malaysia and the system composed of the catchment (roof), gutter, pipe, steel tank and the treatment unit. From 20 different rain events, the collected volume of rainwater in the tank ranges between 0.4 m^3 and 2 m^3. The daily water consumption by student was monitored for one month and compared with the collected rainwater volume. Samples of rainwater was collected from the gutter of the rainwater harvesting system and standard analysis was conducted in the laboratory in order to check the quality of rainwater. The main tests conducted on the rainwater are pH, turbidity, BOD_5, dissolved solids, total solids, total coliform, lead,..etc. The rainwater was found to be acidic in nature (pH < 7).

Keywords: Rainwater harvesting system, storage, demand, urban areas

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 was only doubled and the demand of the agricultural sector is almost 70% of the total demand [1]. The rate of the growth in the urban area is about four times that of the rural areas. Based on this fact, the concept of sustainability must be considered in planning and management of the available water resources. 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 has 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 to 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 be also collected from open areas and store it in a depression of land or basins. The storage from rainwater harvesting system can be used for portable 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 and based on pilot project in Zambia, Africa, a volume of 10 m^3 of rainwater was collected annually[2].

Climate Change and Rainwater Harvesting

Alteration of environment due to global weather change brings about extreme climate events such as drought and flood. Observation showed that drought and flood affected the water resources utilization for various purposes. As a result, many countries adopting strategies to conserve the available water resources including promoting the usage of rainwater harvesting technique for landscaping and agriculture. Recently, many regions around the world adopted rainwater harvesting to reduce the impact of climate change on water supply. These regions are India, South America, Arabian Peninsular, North America, Europe, and Asia-Pacific. Construction of rainwater harvesting structures are practices adopted to overcome drought periods in the above mentioned regions. In South America, outcomes of several studies highlighted climate variability over the continent may lead to reduction of 20 to 40% in rainfall [3]. Rainwater storage in lowlands was a major source of water supply during the dry season in many regions in the world. In Arabian Peninsular, due to aridity and consequent decline in groundwater levels, rainwater was used to recharge the groundwater and impounding structures which helped in the management and food production and enhancement of pastures and promoting vegetation beside the conservation of the environment. In India, climate fluctuations, including large spatial variation in Holocene monsoon and temperature are now well-resolved. For example, it is predicted that wintertime rainfall may decline by 5 to 25% and may lead to droughts during the dry summer months for incoming decades. Traditional village tanks, ponds and earthen embankments numbering more than 1.5 million, still harvest rainwater in 660,000 villages in India and encourage growth of vegetation [3]. Indeed, India has a long sweep of history on management of rainwater harvesting systems. As the aridity increased, people intensified the usage of rainwater harvesting. Recently, impacts of climate-change and global warming on natural systems are becoming clearly visible.

Contemporary Relevance and Advantages of Rainwater Harvesting

Jackson [4] gave many reasons for the relevancy of recent adoption of using rainwater harvesting to overcome the increasing demand of water beside the global weather changes. These reasons are (1) over half of the accessible freshwater runoff globally is already appropriated for human use; (2) more than 1 billion of people currently lack access to clean drinking water and almost 3 billion of people lack basic sanitation services; (3) because the human population will grow faster than increases in the amount of accessible freshwater (per capita availability of freshwater will decrease in the coming century); (4) climate change will cause a general intensification of the earth's hydrological cycle in the next 100 years, with generally increased precipitation, evapotranspiration, occurrence of storms and significant changes in biogeochemical processes influencing water quality. In the next 30 years, projected increase in the population is much higher than the percentage of accessible run off during the same period. Under such circumstances, harvesting rain shall be crucial. Recently, impacts of population growth, development, and climate-change and global warming on natural water resources systems are becoming clearly visible. So, efforts are needed to encourage innovative policy including managing the water demand and promoting rainwater harvesting system. Traditionally, such systems have been integrated with agro-forestry and ethno-forestry practices, and remain useful in contemporary conservation and ecological restoration of degraded ecosystems. A systematic support to local innovations on rainwater harvesting could provide substantial amounts of water and reduce demand on water supply systems. For example, a hectare of land in an arid region with just 100 mm of rainfall annually, could theoretically yield 1 million liters of water per year from harvesting rainwater. Simple local practices such as using ponds and earthen embankments to store rainwater can be considered in rural areas. For instance, rainwater harvesting system in Sudan offers agricultural production security and also raises the nutrient limited yield from 150–250 to 650 kg/ha [3]. Widespread arsenic poisoning is another case point where rainwater harvesting has a great potential possible solution. In West Bengal and Bangladesh, alluvial aquifers used for public water supply are polluted with naturally-occurring arsenic, which adversely affects the health of millions of people by increasing the risk of cancer. Rainwater harvesting is a better option to provide arsenic-free, safe water in a cost-effective and accessible manner, particularly for drinking and food preparation. We must, however, address several challenges effectively to make rainwater harvesting efficient, particularly treatment of harvested rainwater in areas where pollution is uncontrolled. For instance, it is now possible to use nanofiltration for the removal of hardness, natural organic material, micropollutants such as pesticides, viruses bacteria, salinity, nitrates and arsenic. With an insightful policy, rainwater harvesting can be promoted as a strategy for achieving sustainability and conservation of water resources around the world and in an era of intensive climate change.

Domestic Usage of Rainwater Harvesting

Presently, the water supply systems have improved but the demand is increasing due to the population growth, and development. The prolonged dry period due global weather change can be considered as another factor effecting water supply. The available water resources are limited and/or seasonal, which made the experts working in the water sector to search for solutions to the water shortage. Many countries around the world are facing water shortages. Optimization of water usage and the conservation of water as a natural resource can help to overcome water shortage. Rainwater can be used for potable and non-potable uses. The potable uses include drinking, bathing, and cooking and dish wash. Usually the rainwater used 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.

Quantitative and Qualitative Assessment

Ideal domestic rainwater-harvesting systems generally 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 [5]. Most of the rainwater harvesting systems around the world are composed of the roof, gutter, down pipes, and collecting tank. 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 [6]. The formula was modified by Mohammed *et al*. [7] to fit the Malaysian condition. The modified formula is presented below:

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

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 based on an average annual rainfall depth of 2500 mm, and with a system collection efficiency of 75% as given by TNRCC [6].

Equation (1) is applied to compute the volume of rainwater collected from a roof of a house located in the state of Selangor, Malaysia. The size of the roof catchment is 85 m^2 and the computed volume is found to be 0.5 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 [8]. According to the guidelines of the Ministry of Housing, Malaysia an average of 5 persons normally occupies a house in the state of Selangor [9]. Based on recommendations by TNRCC [6], the estimated daily water consumption for a house in the state of Selangor was found to be 1.25 m^3. Shaaban *et al*. [10] found the average water use for facilities using rainwater in Kuala Lumpur, Malaysia is equal to 0.445 m^3. This volume represents the rainwater consumption for washing clothes, toilet flushing, and general cleaning only the rainwater was not subjected to any treatment. 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 to physical 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, cleaning floor, car wash, 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 [11]. Heavy metals such as lead are potential hazards especially in areas of high traffic density or in the vicinity of heavy industries ([12],[11]). Organic chemicals such as organochlorines and organophosphates used in biocides can also contaminate rainwater. Although serious atmospheric contamination of rainwater is normally limited to urban and industrial locations, studies in the north eastern of United States revealing the presence of pesticides and herbicides in rainwater do give some cause for concern [13]. Despite the numerous sources of atmospheric pollution, in most parts of the world, especially in rural and island locations, levels of contamination of rainfall are low. Most contamination of rainwater occurs after contact with the catchment surface (roof or ground) and during subsequent delivery and storage [14]. Matt and Cohen [15] recommended six common water quality tests to be performed on water samples to obtain the background on water quality relevant for rainwater harvesting. The proposed tests for rainwater samples are pH, turbidity, conductivity, hardness, total suspended solids, and coliform colony count. Figure 1 shows the levels of the mentioned six parameters in the water samples as given by Matt and Cohen [15]. Pushpangadan et al. [16] conducted chemical and bacteriological analysis for samples of rainwater in India. They found that the rainwater contained E.Coli bacteria. Out of 30 samples only 2 samples were E.Coli free. They found that as many as 70% of samples had E.coli less than 100 count/100 ml. So, E.coli was present in the 94% of rainwater samples.

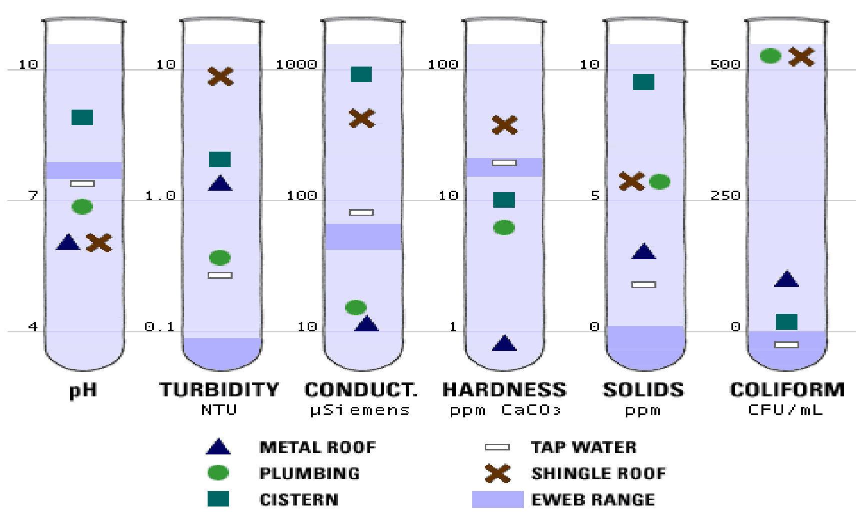


Figure 1: Values of six parameters for various water samples [15]

Rainwater Harvesting System

A rainwater harvesting system was installed at the Faculty of Engineering, Universiti Putra Malaysia and the main objectives from the system installation are to determine the optimum tank size and to study the quality of the collected rainwater. The components of the system are roof catchment (100 m^2), first flush unit, steel tank, PVC pipes (150 mm diameter), and treatment unit. 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 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 were fluctuated. 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 give 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 form 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. The storage of the rainwater in the tank is compared with the consumption of water for non-potable uses (water consumption in the washrooms) and it found that the storage higher than the consumption in many times. However, it found that the storage was either equal or lower than the consumption in another times as shown in Figure 3.

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/100mL	1	0
Lead	mg/L	0.006	<0.003

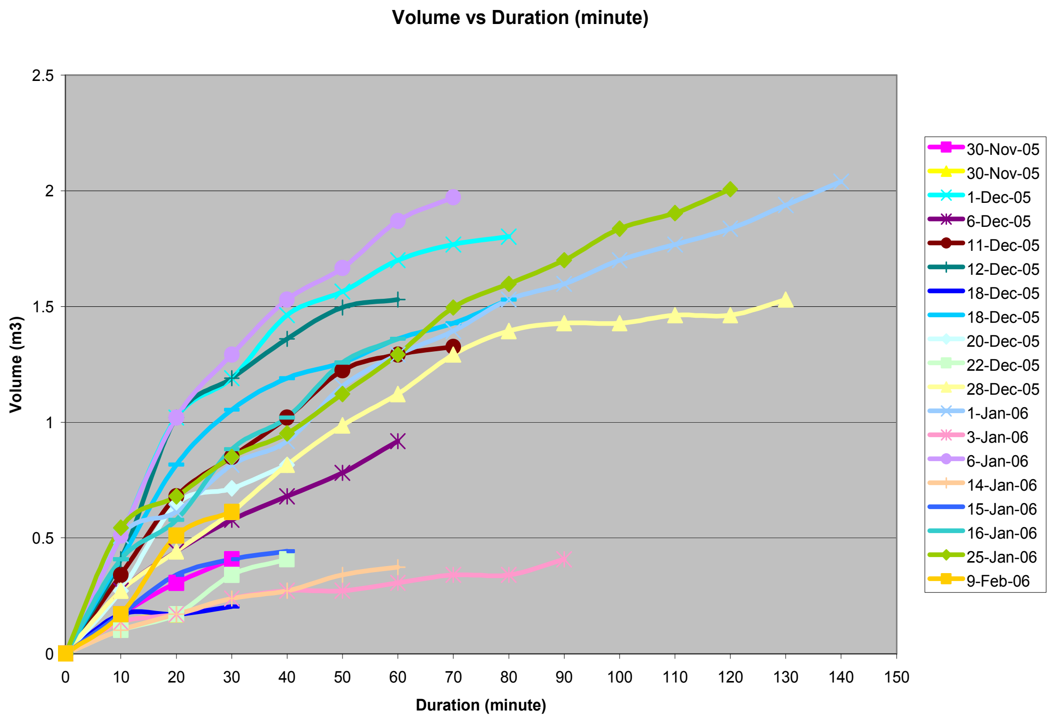


Figure 2: Variation of the collected volume of rainwater with the time

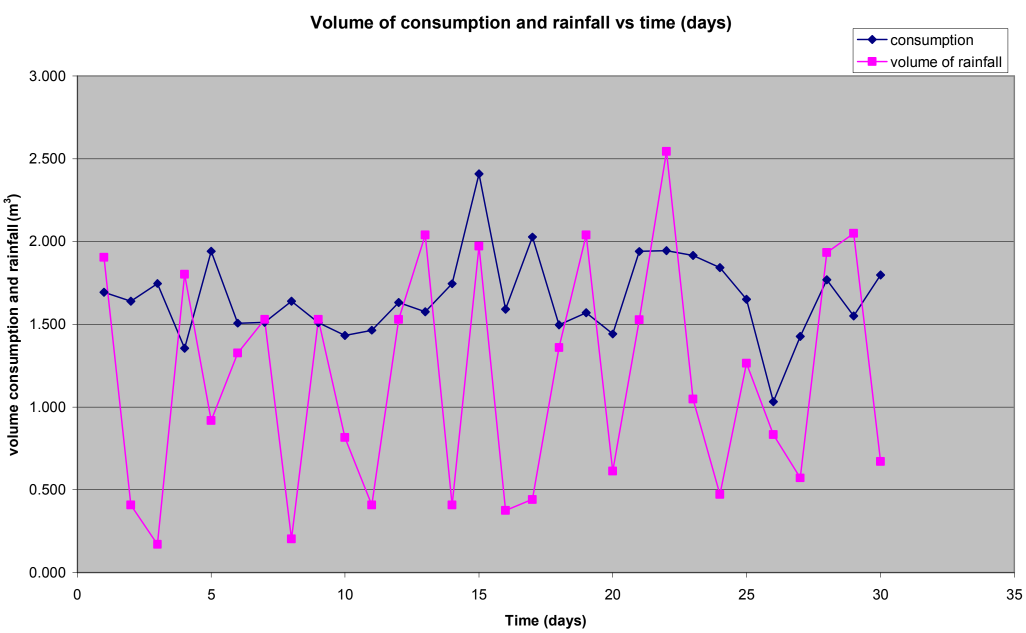


Figure 3: Comparison between the storage of rainwater and water demand for non-potable uses (Wash room)

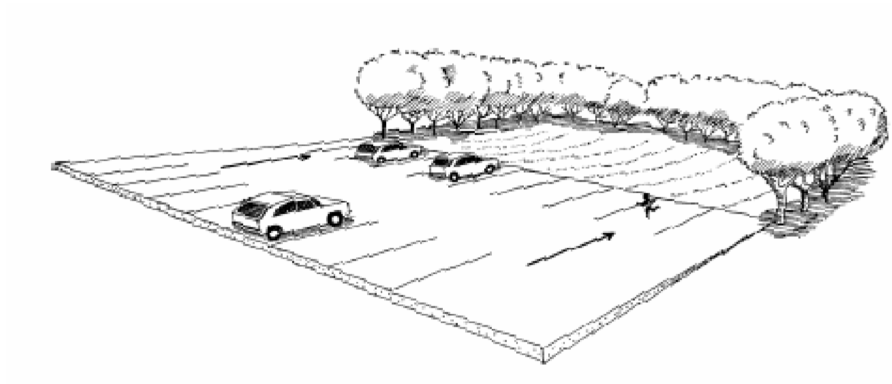
Rainwater can be captured, diverted, and stored for the purpose of using it for plant irrigation. The rainwater harvesting system may be suitable for irrigating farms and Landscapes. The landscapes can be divided into large-scale areas such as parks, schools, commercial sites, parking lots, and apartment complexes. Also it can be suitable for small-scale residential landscapes (Figure 4). A rainwater harvesting system for irrigation purposes has three components, namely the supply source (the catchment), the demand (landscape water requirement), and the conveyance system (system that moves the water to the plants) [17]. Storage can be added to the system if necessary. The volume of rainwater planned to be used for irrigation is 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 for irrigation or stored) form a catchment with fully impervious ground surface compared with a catchemt of pervious ground surface. The selected type of plant, age, size, and spacing between successive plants are factors which contribute in the success of using rainwater for irrigating 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 frequent irrigation. 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 irrigation. Water used for irrigating plant of a landscape from a rainwater harvesting system can be determined by having a good recorded for both yield and consumption. Water saving due to employing rainwater harvesting system can be determined by the following formula:

$$\text{Annual Water Saving} = V_1 - V_2 \quad (2)$$

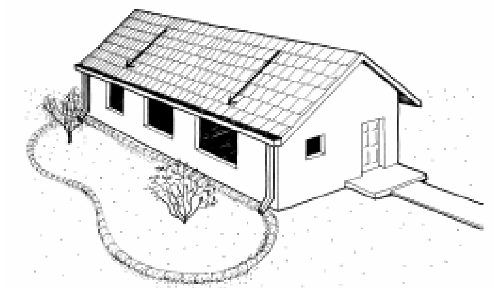
where V_1 is the volume of water pre construction of rainwater harvesting system, and V_2 is volume of water post construction of rainwater harvesting system.

Environmental and Economical benefits

Using rainwater for irrigation can reduce the water consumption. Furthermore, if native and desert-adapted plants are used for landscaping, rainwater harvesting becomes an effective tool for water conservation. Usage of rainwater harvesting means the provided irrigation water is not taken from storage allocated for municipal water supply [17]. There are many benefits of using rainwater harvesting for irrigation, and these benefits are to reduce groundwater exploitation, to reduce flooding, to control erosion and to improve water quality by holding storm runoff on the site (on site detention), and cost reduction. Rainwater is a clean source of water for plants (free from salt). As a result, rainwater harvesting can reduce salt accumulation and contribute in a good soil environment for root growth. The salt concentration in root zone of plants is reduced when collected rainwater percolates deep into the soil and diluting available salt in this zone. This will result in greater root growth and water uptake, which increases the drought tolerance of plants. Limitations of water harvesting are few and are easily met by good planning and design.



42a- Rainwater harvesting from irrigating plants in a car park



4b- Rainwater harvesting for irrigating plants of a house landscape

Figure 4: Rainwater harvesting for landscaping [17]

Types of Rainwater Harvesting Systems for Irrigation

Water harvesting systems for irrigating plants are ranging from simple to complex. A simple system usually consists of a catchment area from which the rainwater can be harvested, and a water conveyance system by which rainwater transfer to the plants and operates by 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 roof. Gravity moves the water to where it can be used [17]. 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 is gently sloped. Hillsides provide a perfect situation for moving water from a catchment to irrigated area. Channels, ditches, and swales all 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 t 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 irrigation water in an average year where the surplus volumes of rainwater can be stored in a tank and then be used for irrigation between rainfall events or at dry period. 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 not dependable. 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.

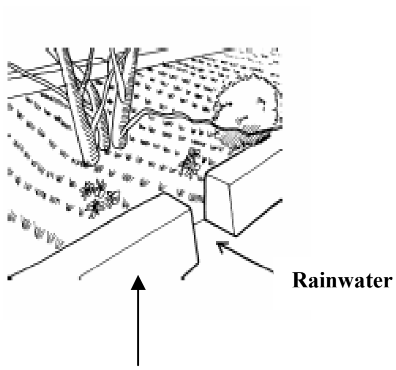


Figure 5: Rainwater for landscaping from curb cut [17]

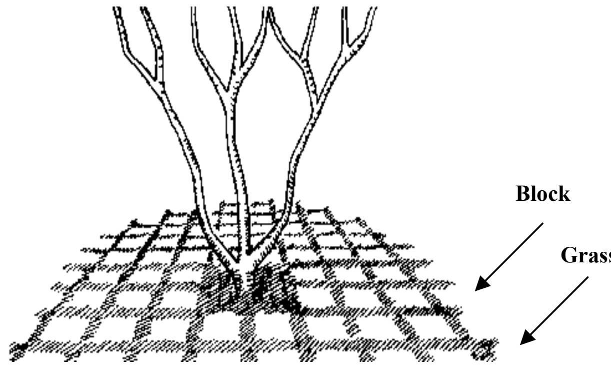


Figure 6: Pervious paving block with grass[17]

Determination of Adequacy of Rainwater Harvesting System for Irrigation

To determine the amount of irrigation water available from storage of a rainwater harvesting system and also the supplement volume of irrigation water 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 following equation:

$$S = A \ x \, R \, x \, C \qquad (3)$$

where *S* is monthly yield of rainwater harvest, *A* is catchment area, *C* is runoff coefficient, and *R* is the monthly rainwater depth. Typical values of runoff coefficient is given in Table 2. Although in reality the amount of water available fluctuates on a daily basis but 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:

$$D = ET_o \text{ x } \beta \text{ x } A \qquad (4)$$

where D is monthly water demand or volume of irrigation water, (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 yield and demand for both new and established landscapes. In case that all the units of the variables used in m^2 and m then the unit of both yield and demand will be in m^3. 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).

EXAMPLE

Rainwater harvesting system utilizes 305 m^2 roof area with a runoff coefficient of 0.9 is used to irrigate low water use plants (plant factor is 0.26) which are distributed in landscaped area of 135 m^2. The recorded monthly rainfall depths and the plants evapotranspiration is shown in Table 3.

Table 2: Typical values of runoff coefficients[17]

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

Computation of yield and demand were conducted in order to present the adequacy of the rainwater harvesting system to irrigate an area of 137 m^2, mass curve of the case study is shown in Figure 7. 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 would be required to supplement the storage in order to supply the plants with enough irrigation 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 with the second year the rainwater storage has built up and there will be enough harvested rainwater to irrigate the plants of the landscape unless a drought occurs. This is attributed to the accumulated volume of rainwater during winter which is not all used up in winter and also due to low rates of evapotranspiration from plants at winter months. So the storage of rainwater during winter months can be saved for summer months. In winter months, overall storage will increase and yield exceeded demand. Each site presents its own

set of yield and demand amounts. 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 ages and its 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 irrigation or watering the 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 used supplementary water source.

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

Conclusions

Demand on water resources witness a substantial increase due to development, population increase, and global weather change. Adopting the concept of sustainability and conservation of water resources can help to cope with the global water shortage. Promotion of rainwater harvesting technique for domestic, landscaping, and agriculture can help to reduce the demand on water resources. Rainwater harvesting systems used in housing schemes can provide water for potable and non-potable uses. The potable uses include drinking, bathing, and cooking and dish wash. 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 contain 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 is different from place to place depending on the weather condition. In a tropical country like Malaysia it is easy to collect 2 m^3 in a single rain from 100 m^2 roof catchment. The data collected form the rainwater harvesting system installed at the faculty of Engineering, Universiti Putra Malaysia revealed that volume collected form from a single rain can meet the consumption of water for non-potable uses. On the contrary,

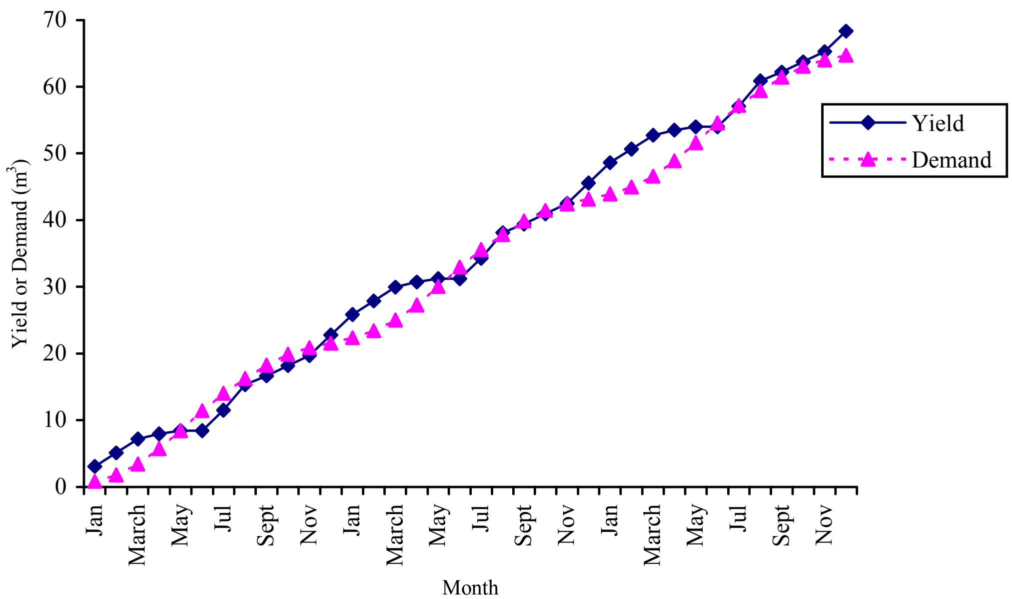


Figure 7: Use of mass curve to determine the possible yield

from rainwater harvesting for irrigation

a volume of 10 m^3 was collected annually in Zambia, Africa from a roof of a same size. Rainwater harvesting can also be used for landscaping and agriculture. Plants and the grass used for various types of landscaping can be irrigated by using rainwater harvesting. The rainwater used for irrigating plants are salt free and this will contribute to creates a healthily environment for the root to grow. Also Rainwater harvesting can reduce the water pollution and conserve the environment by controlling the erosion and reduce the sediment concentration in the storm runoff. 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.

REFERENCES

1. Appan, A. (2000) *Trends in Water Demands and the Role of Rainwater Catchment Systems in the Next Millennium,* Division of Environmental Engineering and Water Resources, School of Civil and Structural Engineering, Nanyang Technological University, Singapore.
2. Handia, L., Tembo, J. M., and Mwindwa, C. (2002) Potential of Rainwater Harvesting in Urban Zambia *proceedings of 3rd WaterNet/Warfsa Symposium*, Dar Es-Salaam.
3. Pendey D.N., Gupta A. K., Anderson D.M. (2003). "Rainwater Harvesting As An Adaptation to Climate Change" Journal of Current Science, 85(1), 46-59.

4. Jackson R. B. (2001). “Water in Changing World” Journal of Eco. Appl., 11, 1027-1045.
5. Texas Water Development Board, TWDB. (1997) *Texas Guide to Rainwater Harvesting*, 2nd Edition., Austin, Texas, USA.
6. Texas National Resources Conservation Commission, TNRCC. (2003) *Manual of Rainwater Harvesting or Collection*, Austin, Texas, USA.
7. Mohammed T. A., Mohd. Noor M. J., and Ghazali A. H. (2004) Quantitative and Qualitative Analysis for Rainwater Harvesting System of Experimental House in Malaysia, *Proceedings of the International Conference Enviro 04*, Sydney, Australia.
8. Department of Irrigation and Drainage Malaysia, DID. (2000) *Urban Stromwater Management Manual for Malaysia,* Vol. 4, 5 and 9, Kuala Lumpur, Malaysia.
9. Ministry of Housing, Malaysia. (1999) *Guidelines for Installing a Rainwater Collection and Utilization System*, Putra Jaya, Malaysia.
10. Shaaban, A. J., Kardi J., and Awang, S. (2002) Rainwater Harvesting and Utilization System for A Double Story Terrace House at Taman Wangsa Melawati, Kuala Lumpur, *Workshop of Rainwater Harvesting as a Tool for Sustainable Water Supply and Stormwater Management*, Kuala Lumpur, Malaysia.
11. Thomas P. and Greene G. (1993) Rainwater Quality from different Roof Catchments, *Water,Science and Technology*, Vol. 28, No. 3/5, pp291-299.
12. Yaziz M., Gunting H., Sapiari N. and Ghazali A. (1989)Variations in Rainwater Quality from Roof Catchments, *Water Research*, Vol. 23, pp761-765.
13. Richards R., Kranmer J., Baker D. and Krieger K. (1987) Pesticides in Rainwater in the northeastern United States, *Nature,* Vol. 327, No. 6118, pp129-131.
14. Waller D. (1989) Rain Water -An Alternative Source in Developing and developed Countries, *Water International*, Vol. 14, pp27-36.
15. Matt A., and Cohen J. (2001) *Harvesting Rainwater a Case Study,* Department of Architecture, University of Oregon, USA.
16. Pushpangadan K., Sivanandan P., and Joy A. (2001) Comparative analysis of water quality from DRWH and traditional sources: A case study of Kerala, India, *Proceedings of the Rainwater Harvesting Conference*, Delhi, India.
17. Waterfall, R. (1998) Harvesting Rainwater for Landscape Use, *Arizona Department of Water Resources*, First Edition, Arizona, USA.