마닐라 지역의 가정용 우수저류시설 잠재가용성 분석

Micah Lourdes A. Felix* / Marla C. Maniquiz** / 서 성 호*** /

김 이 형**** / 정 상 만*****+

Analysis on the Potentiality of Domestic Rainwater Harvesting in Metro Manila

Micah Lourdes A. Felix* / Marla C. Maniquiz** / Sungho Seo*** /

Lee-Hyung Kim**** / Sangman Jeong*****+

요약 : 필리핀의 연평균강수량은 약 965mm ~ 4,100mm로 수자원이 비교적 풍부하다. 필리핀의 최근 급증하는 도시화로 인해, 필리핀의 마닐라 지역에서는 용수의 수요량이 매년 증가하는 추세이다. 용수의 부족을 해소시키기 위해 필리핀의 풍부한 수자원을 적절하게 사용하여야 하며, 이를 위한 방법 중의 하나로 강우의 유출수를 이용하는 우수저류시설이 가용하다고 판단된다. 따라서 본 연구에서는 마닐라 주거지역에서의 우수저류시설에 대한 잠재가용성을 분석하였으며, 그 방법으로는 일별강우, 유역면적, 유출계수, 인구밀도 그리고 용수수요량 등을 매개변수로 사용하는 물수지방정식을 이용하였다. 세 가지 강우조건(연평균 강우중 최소, 중간, 최대값)과 세 가지 화장실종류(저효율식, 재래식, 절수식)에 따른 가정용수탱크 사용에 대하여 분석하였다. 그리고 대상지역에서의 최적의 강우 저장 면적을 결정하기 위해 월류용적을 사용하였다. 연구결과 세 가지 강우조건에서, 재래식과 절수식 화장실이 우수저류시설에 가장 부합되며, 60m^{3}저류용량의 탱크는 3개월간 90가구의 용수수요를 충분히 공급 가능 하다고 나타났다. 본 연구를 통해 주거지역의 장기간 용수수요를 충족시키기 위해서는 저류탱크 용량은 1,100m^3~2,500m^{3}이 적당하다고 판단된다.

핵심용어 : 마닐라, 필리핀, 강우, 우수저류, 물수지

Abstract : The Philippines is known for its abundant water resources such as the rainfall, where it has a mean annual rainfall range from 965 to 4,100mm. Due to the rapid urbanization of the country, the population in Metro Manila has been continuously increasing hence, the demand for a potable water supply also increases. To mitigate the scarcity of potable water supply, utilization of the water resources should be practiced. Rainwater harvesting is one way to utilize the rainfall runoff. This study analyzedthe potentiality of the rainwater harvesting on residential areas in Metro Manila. A water balance method based spreadsheet was used with input parameters including daily rainfall, catchment area, runoff coefficient, population and the water demand. The efficiency of the domestic water tank was analyzedusing the three different climatic conditions (i.e., minimum, median andmaximum annual rainfalls) and three different types of toilets (i.e., inefficient, conventional and dual-flush toilets). Furthermore, the overflow volume was used to determine which size of rainwater storage was more appropriate for the study area. The results of the study showed that for the three types of rainfall years, only the conventional and dual-flush toilets were suitable for the utilization of rainwater harvesting. The utilization of the 60 m^3 storage tank was sufficient for supplying the demandsof the 90 houses only for a small period of time, 3 months. Based from this study, to fully sustain the long-term water demand of the houses, the enlargement of the tank size having a capacity of 1,100 to 2,500 m^3 is ideal.

Keywords : *Manila, Philippines, Rainfall, Rainwater harvesting, Water balance*

+ Corresponding author : smjeong@kongju.ac.kr
* Graduate Student, Dept. of Civil and Envi. Eng., Kongju National University
** Graduate Student, Dept. of Civil and Envi. Eng., Kongju National University
*** Graduate Student, Dept. of Civil and Envi. Eng., Kongju National University
**** Professor, Dept. of Civil and Envi. Eng., Kongju National University
***** Professor, Dept. of Civil and Envi. Eng., Kongju National University

I. Introduction

The Philippines is a tropical country that has two types of seasons, the wet and dry seasons. It has an abundant amount of rainfall with mean annual rainfall of 965 to 4,064 mm. Metro Manila, the regional center of the National Capital Region (NCR), constitutes 13% of the total population of the country with an annual growth rate of 1.8% (National Statistics Office, 2011),population density of 15,617 persons per km^2(Ragragio, 2011), and a minimum requirement for water consumption of 0.14 m^3 per capita per day (Aiga, 2003). Due to this rapid urbanization, both the amount of storm water runoff and the demand for potable water increases resulting to flooding and the scarcity of potable water supply. During dry season, the Philippines experiences water supply shortages due to the insufficient supply coming from the dam and droughts caused by El Niño. Such occurrences can be minimized if the utilization of the rainwater during wet seasons can be used for the dry seasons.

A particular approach to this kind of utilization is known as the rainwater harvesting which is a method of collecting rainfall for domestic water supply, agriculture and environmental management. A rainwater harvesting system (RWHS) consists of three basic componentsnamely the catchment, delivery and storage systems (Worm and Hattum, 2006). The rainwater catchments are impervious surfaces that catch the rainwater delivery systems are responsible for redirecting the harvested rainwater by the catchment to the storage and the storage system is where the rainwater is stored for further distribution to the establishment. For domestic purposes, the rainwater collected can be used for gardening, car washing or for flushing toilets. This is a convenientmethod wherein the only expenditures will be for the storage, but the consumer cansave the money from commercial water supply. Also, this type of water utilization has been practiced in other countries as well, especially countries in arid or semi-arid regions where there is a limited amount of rainfall.

The Republic Act No. 6716 of the Philippines approved in March 1989 states that the construction of rainwater collectors should be done in all *barangays* of the Philippines for an adequate potable water supply (Robles, 1998). The RWHS was first initiated in Capiz Province wherein almost 500 rainwater storage tanks were constructed for agricultural purposes (Global Development Research Center, 2011). Government agencies such as the Department of Public Works and Highways (DPWH) and the Department of Education (DepEd) have organized projects on the installation of RWHS in Local Government Units (LGUs) and public schools in the Philippines. As of February 2011, the DPWH has finished the installation of nearly 93 RWHS in LGUs nationwide (Department of Public Works and Highways, 2011).

The use of a simple spreadsheet based water balance model is a convenient method that can be easily used to determine the performance of a RWHS. The same method was used to investigate the effectiveness of storm water harvesting and payback periodsfor large rainwater tanks and the developed model was used to optimize the size and catchment area for the tank (Imteaz et. al., 2011a). Another study, investigated the reliability of the rainwater tanks in different scenarios (i.e. climatic conditions, roof areas, tank volumes, household water demands and the portion of the total demand that will be filled by the rainwater) (Imteaz et. al., 2011b).

Despite the efforts made by the government institutions on the implementation of the RWHS, further studies discussing the potentiality of the RWHS are needed to prove the applicability of the system in the Philippines. The objective of this study was to analyze the potentiality of the applicability of the RWHS in residential areas in Metro Manila, Philippines using three different types of water demand and types of toilet used (i.e., inefficient, conventional and dual-flush toilets). The most suitable size of the rainwater storage was also analyzed using six different storage capacities.

2. Methodology

A simple water balance model based spreadsheet was used to analyze the potentiality of the RWHS. The water balance was calculated using Eqn. (1).

$$\textit{Water Balance} = \textit{Inflow} - \textit{Outflow} \qquad (1)$$

To achieve a more precise calculation, the daily water balance was determined wherein both the inflow and the outflow were computed on a daily basis. The daily inflow was determined by Eqn. (2) using the daily rainfall data obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2011). The catchment area was assumed to be 4,320 m^2, consisting of 90 socialized duplex houses, each with a catchment area of 48 m^2 (Housing and Land Use Regulatory Board, 2011) and the runoff coefficient of 0.8 was used for smooth corrugated roofs (United Nations Environment Programme, 2011).

$$\textit{Inflow}(m^3) = \textit{Rainfall}(m) \times \textit{Catchment Area}(m^2) \times \textit{Runoff Coefficient} \qquad (2)$$

The outflow was calculated using the daily water demand in Eqn. (3). The total number of the population was based from the number of houses. It was considered that the average household size in the Philipppines was consisted of five persons (Ragrario, 2011); hence, the total population that was used in this study was 450 capita. It wasassumed that the given population was stationary all throughout the study since the study was residential. The values for the average number of flushes per day per capita and the average flush volumes of inefficient, efficient conventional (conventional) and efficient dual-flush (dual-flush) types of toilets, were based on the Water Efficiency Plan of Toronto Works and Emergency Services which were used for estimating water demands for households (Toronto Works & Emergency Services, 2011). The total water volume demand per flush for inefficient, conventional and dual-flush toilets were0.0165, 0.006 and 0.0043 m^3, respectively. It was also assumed that the RWHS started to operate at the start of each year (i.e. January 1).

$$Outflow = Water\ Demand(m^3) = Population(capita) \times ave.no.of\ flushes\left(\frac{flush}{day.Capita}\right) \times flushing\ demand\left(\frac{m^3}{flush}\right) \quad (3)$$

$$Overflow\ Volume = Water\ Balance(m^3) - Size\ of\ the\ storage(m^3) \quad (4)$$

The overflow volume was the amount of rainwater that cannot be harvested due to the lack of volume space of the storage. The overflow volume was the difference between the water balance and the storage size (Eqn. 4). The water balance used was the accumulated water balance. The storage capacity of the tank was initially assumed to be 60 m^3, which was the storage designed by the DPWH and intended for rainwater harvesting (Department of Public Works and Highways, 2011). To further analyze the efficiency of the assumed storage capacity, five additional storage capacities were considered in relation with the base storage design of 60 m^3. The five additional storage capacities were 30, 120, 240, 480 and 960 m^3 corresponding tothe half and twice, four, eight and sixteen times of the base storage capacity, respectively.

3. Results and Discussions

3.1 Rainfall

To have a good comparison on the amount of rainwater that was harvested, three different rainfall years or climate conditions were considered. Based on the nine annual rainfall year data between 2000 and 2008 shown in Fig. 1, three different rainfall years were selected with the minimum (2004), median (2003) and maximum (2000) yearly rainfall amount. The maximum rainfall was obtained in 2000 having a total annual rainfall of 3,450 mm. Furthermore, the maximum number of tropical cyclones in one year was produced in 2000 resulting to five tropical cyclones while the minimum rainfall year in 2004 only had three tropical cyclones with an annual rainfall of 1,549 mm. The average annual rainfall between 2000 and 2008 was 2,147mm wherein almost 70% of the rainfall years werelower than the average annual rainfall. The two extreme rainfall years were compared. Hence, the annual rainfall of the minimum year was just 45% of the annual rainfall of the maximum year, a difference of 1,900 mm was observed. The rainwater that can be harvested during the maximum year was almost twice the amount of that of the minimum year.

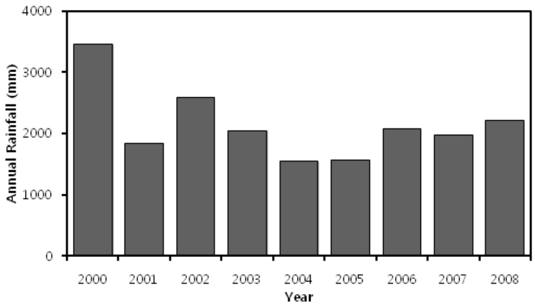

Fig. 1 Annual rainfall from year 2000-2008.

The daily rainfall data for each selected year was used to determine the daily inflow of the water balance method, the rainwater harvested was used to supply the daily demands. It was shown in Fig. 2 that the wet season started from May to November followed by the dry season in December to April. Majority of the days in a year in the Philippines wererainy, which consists of 60% of the total year while the rest of the days in a year were dry.

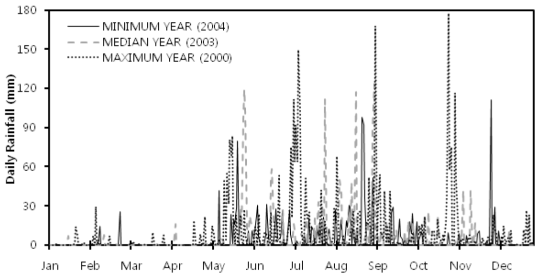

Fig. 2 Daily rainfall of the three rainfall years.

3.2 Volume Demand

Three types of water consumptions were used for the comparison of three toilet types (i.e. dual-flush, conventional and inefficient toilets). These types of water demand were used due to the fact that the type of toilet used in residential houses in the Philippines is not limited to one kind of toilet type. Since the cost of purchasing a dual-flush or conventional toilets are costly, not all residents can purchase this kind of toilet. Hence, the inefficient type of toilet, which is the cheapest, is still used in some residential houses in the Philippines, especially in low income households. Fig. 3shows that if given a daily allowance of water supply having a total volume of 100 m^3 16, 22 and 62 m^3 of water wereconsumed by dual-flush, conventional and inefficient toilets, respectively. It was evidently shown that the volume demand of the dual-flush efficient toilet was almost four times lesser than the volume demand of the inefficient toilet; thus, it could consume less water and money. However, due to the high cost of the dual-flush toilets, not all houses in the Philippines use dual-flush toilets. Instead, majority of the houses in the Philippines uses the conventional type of toilet, especially for middle-class families, while the use of the inefficient toilets is still being utilized by low-earning families.

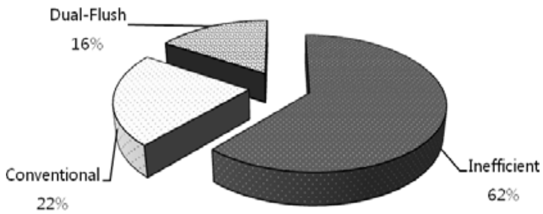

Fig. 3 Flushing volume demands.

3.3 Water Balance

Using the three different rainfall years selected from year 2000 to 2008 (i.e., 2004, 2003 and 2000 as the minimum, median and maximum rainfall years, respectively) the inflow for the water balance was calculated using Eqn. (2). Since the water demand is a function of the population, and it was assumed that the total population of the household was fixed consequently, the water demand throughout the year was stationary. Assuming that the storage was sufficient to store all the rainwater harvested, the accumulated water balance for the three toilet types are shown in Fig. 4 (a), Fig. 4 (b) and Fig. 4 (c). The plots indicate that at the beginning of the year, since the rainfall is minimal, the supply was insufficient to fully provide the overall daily demand. The accumulated water balance started to increase from May signifying that the system was gradually supplying the daily demand. If the accumulated water balance was negative, it means that the outflow was larger than the inflow. On the other hand, if the accumulated water balance waspositive, it means that the inflow was larger than the outflow therefore, the inflow volume was redirected to the storage.

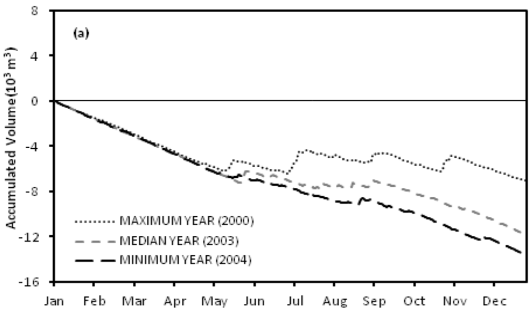

Fig. 4 (a) Accumulated water balance (inefficient toilet)

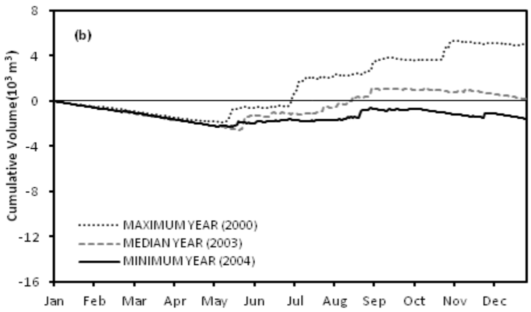

Fig. 4 (b) Accumulated water balance (conventional toilet)

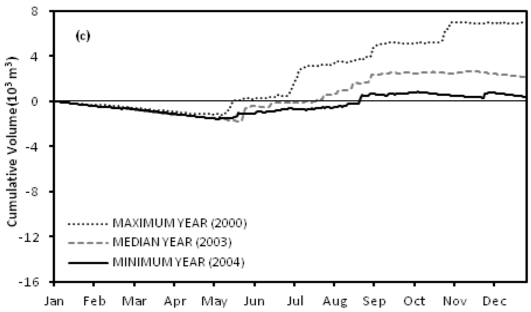

Fig. 4 (c) Accumulated water balance (dual-flush toilet)

Fig. 4 (a), accumulated water balance for inefficient toilet, shows that the use of the RWHS alone cannot sustain the flushing demand of the inefficient toilet implying that the demand for flushing this kind of toilet will mostly depend on the water supply from the service provider. Fig. 4 (b), accumulated water balance for conventional toilet, shows the accumulated water balance for conventional toiletswherein, the minimum year was insufficient to supply the daily demand for this kind of toilet. The largest negative and the largest positive accumulated water balance volumes of the conventional toilet for the median and maximum years were 2,548 and 1,130 m^3 and 1,896 and 5,463 m^3, respectively. The minimum year hasnegative values of 2,283 and 19 m^3 for both the lowest and the highest values of the accumulated water balance, respectively. Therefore, only the two rainfall years (i.e., median and maximum rainfall years) could supply the daily demand of using of conventional toilets. In Fig.4 (c), accumulated water balance for dual-flush toilet, all the three rainfall years were sufficient to supply the daily demands for dual-flush toilets. The minimum year, has the lowest values among the three rainfall years with values of 1,563 and 840 m^3 for the lowest and highest values, respectively. The system had the largest demand of 1,769 m^3 during the median year and a highest accumulated volume of 7,031 m^3 during the maximum year.

3.4 Storage Tank Capacity

It was considered that the group of houses has a common storage tank for storing all the rainwater harvested. The overflow volume was calculated to determine profile of the amount of water that was not utilized.

Six storage capacities were selected to analyze the overflow of the conventional type of toilet, since it is a commonly used type of toilet used for houses.

Fig. 5 (a) and Fig. 5 (b) shows the daily profile of the accumulated overflow volume for storage sizes of 30, 60, 120, 240, 480 and 960 m^3 for the median and maximum rainfall year, respectively. Fig. 5(a), overflow for the median year, shows that the storage started to overflow in August, three months right after the start of the rainy season. For the storage sizes of 30, 60, 120 and 240 m^3, the storage overflowed during almost five months (i.e., mid-August until at the end of December), while the 480 and 960 m^3 storage tanks overflowed only for three and two months, respectively. It is shown Fig. 5(b), overflow for the maximum year, that the storage overflowed at the start of July, one month earlier than that of the medium year. Also, all six storage sizes overflowed for six months (i.e., from July to December).

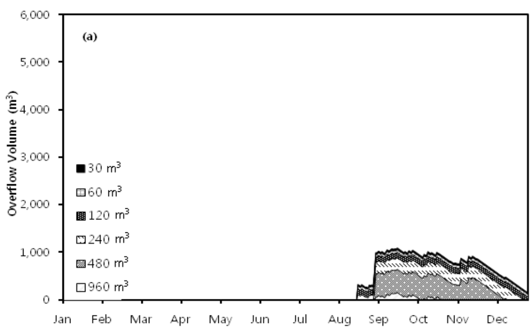

Fig. 5 (a) Overflow volume profile of different tank sizes (median year)

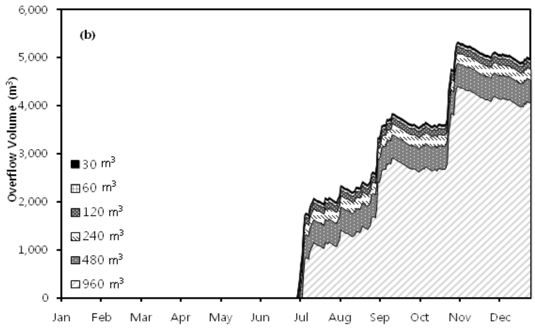

Fig. 5 (b) Overflow volume profile of different tank sizes (maximum year)

4. Conclusion

This study analyzed the potentiality of the rainwater harvesting system applicable in residential areas in Metro Manila, Philippines. The water balance method was used todetermine if the amount of rainfall that can be harvested is sufficient to supply the daily demands of the three types of toilets in three different rainfall years. The results showed that from the three types of toilets, the inefficient is not beneficial in any way with respect to rainwater harvesting. However, if all houses usingeither the conventional or dual-flush types of toilets, it is feasible to use the rainwater harvesting system for supplying the yearly demand of all 90 duplex houses in Metro Manila. Also, based on the graphs, the continuous use of the rainwater harvesting system can utilize the overflow volume during the rainy season for the summer season. For the type of tank size, the utilization of the 60 m^3 storage is sufficient but inefficient. The tank was sufficiently providing for asmall period of time however, the enlargement of the tank size can be considered to fully sustain the water demand of the houses throughout the years. For the tank size, the median year and the conventional toilet were considered since both of these are normal climate and commonly used, respectively. A tank size having a capacity range of 1,100 to 2,500 m^3 is recommended based on the accumulated water balance of the median year for conventional toilet type of demand. The recommended size of the storage tank has a minimum value of 1,100 m^3 to utilize the amount of rainwater harvested and 2,500 m^3 to sustain the highest accumulated yearly demand for using the conventional type of toilet. This tank sizecould contribute to sustain then demands of the houses and prevent the spillage of the rainwater that can be harvested. The overflow volume can be utilized for other purposes such as, gardening, groundwater recharge and for industrial use. This study can be used to assess the future application of the RWHS on residential houses for flushing toilets. Hence, the use of the simple daily water balance methodbased spreadsheet can be used to evaluate the rainwater harvesting system in a specific establishment.

References

Aiga, H. (2003). Household Water Consumption and the Incidence of Diarrhoea. Accessed on: October, 2011. Available at: http://www.emro.who.int/ceha/pdf/Diarrhoea2.pdf

Department of PublicWorks and Highways (DPWH). Port Area, Manila, Philippines.

Housing and Land Use Regulatory Board (HLURB). Revised Rules and Standards for Economic and Socialized Housing Projects to Implement. Accessed on: October, 2011. Available at: http://hlurb.gov.ph/uploads/developers/rule1n2.pdf

Imteaz MA, Ahsan A, Naser J and Rahman A. (2011a). Reliability Analysis of Rainwater Tanks in Melbourne using Daily Water Balance Model. *Resources, Conservation and Recycling.* 56, 80-86.

Imteaz MA, Shanableh A, Rahman A and Ahsan A. (2011b). Optimisation of rainwater tank design from large roofs: A case study in Melbourne, Australia. *Resources, Conservation and Recycling.*55, 1022-1029.

National Statistics Office (NSO). Census. Projected Populations by Sex, Region and Province, and by Single-Calendar Years: 2000-2010 (Medium Series).Accessed on: July, 2011. Available at: http://www.census.gov.ph/data/sectordata/popproj_tab3r.html

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Quezon City, Philippines. Acquired on: October, 2011.

Ragragio, J. M. The Case of Metro Manila. Accessed on: October, 2011 Available at: http://www.ucl.ac.uk/dpu-projects/Global_Report/pdfs/Manila.pdf

Robles, C. (1998). Republic Act No. 6716. Accessed on: October, 2011. Available at: http://www.chanrobles.com/republicacts/republicactno6716.html

The Global Development Research Center (GDRC). Rainwater Harvesting and Utilisation. , Accessed on: October, 2011. Available at: http://www.gdrc.org/uem/water/rainwater/rainwaterguide.pdf

Toronto Works & Emergency Services (TORONTO). Water Efficiency Plan.

Accessed on: August, 2011. Available at: http://www.toronto.ca/watereff/pdf/appa.pdf

United Nations Environment Programme (UNEP). Rainwater Harvesting in the Caribbean. Accessed on: August, 2011. Available at: http://www.unep.org/themes/Freshwater/PDF/RWH%20technical%20sheets.pdf

Worm, J. and Hattum, T. V. (2006). Rainwater Harvesting for Domestic Use. pp 12-13

○논문접수일 : 2011년 09월 15일
○심사의뢰일 : 2011년 09월 16일
○심사완료일 : 2011년 12월 11일