Sigma J Eng & Nat Sci 8 (3), 2017, 209-216

Publications Prepared for the International of Water and Wastewater Management Symposium UKSAY 2016
Uluslararası Su ve Atık Su Yönetim Sempozyumu UKSAY 2016 için Hazırlanan Yayınlar

Research Article / Araştırma Makalesi

AN EVALUATION ON RAIN WATER HARVESTING AND GREY WATER REUSE POTENTIAL FOR ANKARA

Kamil AYBUĞA*, Gamze YÜCEL IŞILDAR

Gazi University, Institute of Science and Technology, Environmental Science Department, ANKARA

Received/Geliş: 23.03.2017 Accepted/Kabul: 25.03.2017

ABSTRACT

Rain water harvesting and grey water re-use are widely known applications both for water supply and water end use optimisation. In this study, possibility of water savings evaluated in case of grey water re-use and rain water harvesting taken as an integrated system. Precipitation values and domestic water end uses are required to calculate total water savings of any arrangement in water use model. An estimated distribution of domestic water end use estimated conducting a literature survey on related studies. Potential rain water harvesting volume for Ankara city was calculated using available precipitation data. This water volume was accepted as a secondary water resource for drinking water utility. Rain water harvesting and grey water re-use requires storage. Required reservoir volume to store rain water was calculated under two different scenarios. In the first scenario, washing machine and dishes washer was fed by rainwater, and in the second one an extra volume for irrigation was reserved. Reservoir volumes to store effluents of washing machine, dishes washer, bathing, shower and faucets were calculated under two different scenarios. In this way, water use scenarios were shaped based on four different options. It is estimated that rain water harvesting method is capable to feed only 70% of total domestic consumption in Ankara. Thus, system should be designed on low demanding side. In this case, it is not feasible to select corresponding reservoir volume. However, water supply still will be assured 90% even if the reservoir volumes selected in a half. It is estimated that rain water harvesting and grey water reu-se altogether offer a chance of water savings between 40% and 46%.
Keywords: Water use model, domestic end use, grey water reuse, water savings, rainwater harvesting.

1. INTRODUCTION

Extraction, treatment and distribution of potable water causes dramatic impacts on natural resources. Furthermore, operation of drinking water supply and distribution systems requires intensive energy usage. Continuous expansion of the system is causing more greenhouse gas emissions. The demand for clean water is increasing worldwide because of population growth and rise on living standards. In Turkey, potable water distribution utilities are continuously growing larger due to increase of municipal population. An important fraction of total extracted potable water (36%) [1] is not being delivered to end users, because of seepage loss.

The use of drinking water for all household requirements causes to deterioration of water resources. In order to prevent this deterioration, it is vital to consider optimization of residential

* Corresponding Author/Sorumlu Yazar: e-mail/e-ileti: kamil.aybuga@gazi.edu.tr, tel: (312) 202 37 25

end uses of water.Optimization of domestic water end use is shaped based on a few applications."Rain water harvesting" and "grey water re-use" are viewed as potential substitutions for potable water for various domestic end uses [2], [3].

The main objective of this study is to evaluate the potential and feasibility of application of greywater recycling and rainwater harvesting systems for domestic water use for Ankara urban area. In this context, recent data for the average urban household water use, water consumption associated with domestic water use rates in Ankara province were obtained. All residential applications with domestic water use rates determined from the literature. Calculated water end uses were processed with different rain water harvesting and grey water re-use combinations. By this way, it would be possible to estimate the degree of water savings using rain water as a secondary water resource. Eventually the water use model to fulfill the domestic water requirements was established.

2. STUDIES

2.1. Assumptions and System Boundaries

The main objective of this study is to determine the possible annual water savings rates upon a "single family" house. In this study, household size corresponds to 4 persons, which is approximately (being originally 3.6) average Turkish family household size according to recent official information [1]. Results calculated based on 4 persons of household are given as weekly, monthly and annually. Water introduced to household via both rain water harvesting and potable water utility is being re-used within greenhouse and rain garden following the first use for indoor activities. Any fraction which is not suitable for re-use is directed to waste water collection system.

2.2. Characterization of Domestic Water End Use

In general, domestic water requirements are provided by potable water network or taken from individual wells. Usually each liters of water taken from utility given the water collection network after being used just once. "Potable water" is used for all of the domestic water end use without considering if it is really a necessity to use potable water. Despite that, it is not necessary to use potable water for each domestic end use. Still it is a necessity to know the nature of domestic water end uses for commenting any further. According to Gleick, it is vital to supply 50 litres/capita/day in order to maintain good health and sanitation conditions [4]. Thus, it is assumed that domestic end use for a 4-person household should be not lower than 200 litres per day. Starting from the end of 1990s, several studies were conducted in USA and Australia aiming to proportionate domestic water end uses (Table 1). Main criteria for featuring these reviews in the table are their methodology and geographical extent. All studies were using the methodologies combined with data logging, household interview or questionarries and social analyses to reflect human attitude effects on the results. Some results were offering chance to assess the relationship with irrigation or precipitation regyme, while others are giving chance to be focused on main domestic end uses.

Table 1. Domestic water end uses (%) and related studies [5], [6], [7], [8], [9], [10], [11]

	AWWA 1999	Perth 2003	Melbourne 2005	Auckland 2007	Gold Coast 2008	Salt Lake City 2011	WRF 2016
Shower	16.8	15	22	27	33	21	20
Clothes Washer	21.7	13	19	24	19	22	16
Toilet	26.7	10	13	19	13	20	24
Faucets	15.7	7	12	14	17	18	20
Dishes Washer	1.4		1	1	1		2
Bathing	1.7		2	3	4	2	3
Leakages	13.7	1	6	4	1	14	13
Irrigation		54	25	8	12		
Others	2.2		0	0	0	2	3

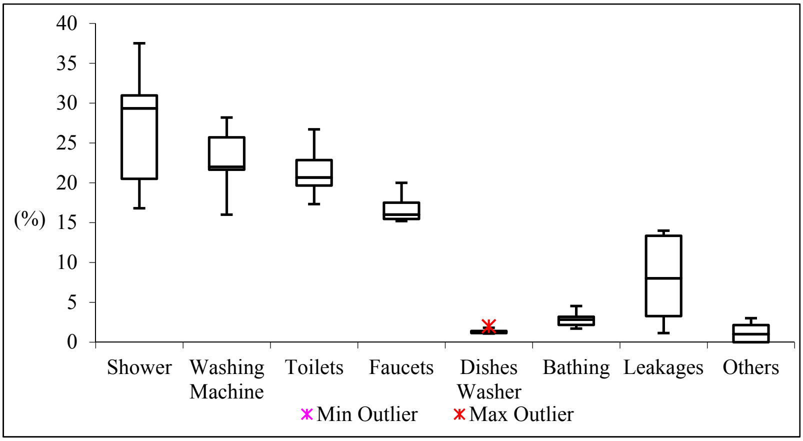

Figure 1. Analysis of water end uses (Produced based on data on Table 1)

Domestic water end uses (as shown in Figure 1) vary occasionally. Water uses for shower, washing machine, toilet and faucets are at the upper side while consumptions from dishes washer, bathing, leakage and others seem to be following lower end side of the curve. Lower side consumptions except leakages seem to vary less. Dishes washer water use is on the low end and having less uncertainity compared to higher end consumptions. Higher end consumptions are more variable because of being affected factors like human attitude, age distribution of inhabitants etc. Despite of the fact that domestic water end uses are highly variable, there is still possibility to distinguish them. In this study, water end uses were proportionated based on the median values of each water end use coming from literature review (Figure 1). Consumption values for washing machine, toilets and faucets correspond to 87 % of total consumption and this big fraction is applicable for any arrangement to achieve water savings.

2.3 Domestic Water End Use Ratio for Turkey

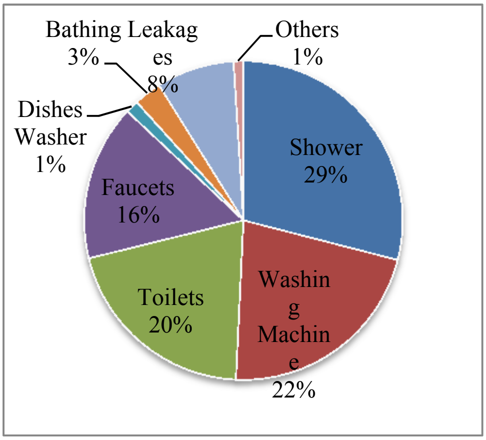

Figure 2. Estimated water end uses

According to recent official data, average extracted volume per capita per day in Turkey was 203 litres for year 2014. It was 211 litre/capita/day for Ankara city [1]. It is presumed that the rate of domestic water use corresponds to 50 percent of total consumption in urban areas [12]. In this case, it is applicable to assume 105.5 litre/capita/day for domestic use in Ankara city. Since the average household size was selected as 4 people, total household water consumption will be equal to 422 litre/day. This consumption value was shared between domestic water end uses (Figure 2).

After calculation of annual consumption volumes, characteristics and composition of each water end use were reviewed by literature. It is concluded that approximately 78% of total waste water could be characterized as grey water (Table 2). Thus, there is a great potential of indoor re-use, considering corresponding grey water fraction.

Only a small fraction about 20% of total waste water could be characterized as brown or black water. However, especially for the water used by faucets, there is a necessity to further research because of cultural differences between USA, Australia and Turkey that affects the end use proportion. For many papers listed in Table 1, there are no detailed proportions for faucets used in bathroom and kitchen. Instead, a sum of total use was presented as “faucet use”. Since there is a different kind of “water using” toilet called “alaturka” in Turkey, an extra faucet adds to the total. Another diversion occurs because of a local “water using version” of western toilet with an extra faucet. These different faucet uses will be additional spots of potable water consumption. Because of information absence for faucet use, it is assumed that each faucet (in kitchen, toilet and bathroom) was using potable water equally.

2.5. Rainwater Harvesting

Rain water harvesting calculations require precipitation data. Precipitation data was taken from Turkish State Meteorological Service. After a short investigation between weather stations, station 17130 was selected due to its broad time period covering years between 1970 and 2015. Selected station was also having minimum fragmented data compared to others.

Rain water harvesting requires storage reservoirs. In this study, required reservoir volume was calculated by using Ripple Method. Ripple method is useful for obtaining economic reservoir volume to supply water continuously [13]. To examine if rain water is enough to meet requirements, daily measured rainfall data was converted to weekly total rainfall (2400 in total). These 2400 values were compared with weekly consumptions which were fixed at 0.69 and 1.00 m^3 under 2 different consumption scenarios (Table 3). Following to first calculations, it is understood that harvested rain water was not enough to meet weekly consumption (422 lt/h/d). Harvested rain water was able to meet the requirement around at a rate of 70%. Thus, requirements were taken as meeting different end use fractions like washing machine, dishes washer and irrigation (Table 3). In order to find required reservoir volume, weekly harvested rain water volume (V_w) (1) was calculated via weekly total precipitation (P, mm) and roof area (A, m^2), where “c” symbolizes collecting surface runoff coefficient and “µ” stands for hydraulic filtration efficiency of the system. Hydraulic filtration efficiency could be equal to 0.95 in case of good maintenance of filters in the system. [13] In this study, it is accepted as 0.90 to stay confident about harvesting efficiency. Reservoir volume is storage volume that system can accumulate harvested water in rainy days. In this case, storage volume that can store maximum accumulated positive sequence. Maximum accumulated positive sequence was calculated by the difference of weekly consumption (Cw) and collected water (Vw) for that time. Storage should be equal to zero if Cw-Vw is equal to zero at the first week of the data sequence (2). Otherwise, storage volume should be equal to the Cw-Wv itself (3). Similarly, storage volume for the following weeks of the data sequence should also follow the same pathway (4), (5). Eventually the selection of reservoir volume requires determining the maximum storage volume corresponding to any time inverval of data sequence (6). [13]

Table 2. Estimated water end uses

End Use	Shower	Washing machine	Toilets	Faucets	Dishes washer	Bathing	Leakages	Others
Daily (lt/day)	122.38	92.84	84.4	67.52	4.22	12.66	33.76	4.22
Annual (m^3)	44668	33886	30806	24644	1540	4620	12322	1540
Characteristic	Grey water	Grey water	Black water	Grey water	Grey water	Grey water	Potable water	Grey water
Composition	Shampoo Soap Organic matter	Detergents Organic matter	Organic matter	Organic matter	Detergents Organic matter	Shampoo Soap Organic matter	Not drained to sewer	Detergents Organic matter

$$Vw = c * P * A * \mu \quad (1)$$

$$St = 0, C(w,t) - V(w,t) \leq 0 \quad , t = 1 \quad (2)$$

$$St = C(w,t) - V(w,t), \ C(w,t) - V(w,t) > 0 \quad , t = 1 \quad (3)$$

$$St = 0, \ S(t-1) + C(w,t) - V(w,t) \leq 0 \quad , t > 1 \quad (4)$$

$$St = S(t-1) + C(w,t) - V(w,t), S(t-1) + C(w,t) - V(w,t) > 0 \ , t > 1 \quad (5)$$

$$Vr = maximum(St), 1 \leq t \leq n \quad (6)$$

Table 3. Rain water harvesting scenarios

	Use	Area (m^2)	Weekly consumption (m^3)	Annual rainwater harvesting (m^3)	Annual precipitation (mm)	Annual demand (m^3)	Reservoir volume (m^3)	Demand fraction	Storage fraction	Efficiency
Scenario1 (97.06 lt/d)	WM + DW	200	0.69	69.50	406.41	36.27	11.69	0.52	0.17	89.00
Scenario2 (143 lt/d)	WM + DW + IR	250	1.00	86.87	406.41	53.33	17.92	0.61	0.21	89.00

WM: Washing Machine, DW: Dishes washer, IR: Irrigation

Because of weekly consumption was fixed for each scenario, requirement for storage only fluctuates by total weekly rainfall. High fraction of total weekly rainfall (94%) harvesting corresponds to precipitations up to 30 mms. It means, in case of harvesting precipitations up to 30 mms, system would be effective more than 90% on catching rainfall. According to many studies, for the low demand side applications, system efficiency was still about 89%, being independent from reservoir volume [13]. Thus, it is possible to select reservoir volume less then ideal reservoir volume which still guaranties 89% system performance.

2.6. Grey Water Reuse

Domestic grey water classified as weak or strong grey water in accordance with its organic matter content. Effluents from faucets, shower and bathtubs, washing machines and also kitchen sink are called as weak grey waters. Weak grey water usually contains organic matter which is coming from human body. Besides, some of the indicator organisms including coliforms, E. coli and enterococci were found in grey water [14]. For this reason, it is a requirement to handle grey water cautiously and apply pretreatment in some degree, in order to prevent possible health problems. In this study, grey water considered to be handled with closed pipe systems without any contact with human body or household stuffs.

Grey water undergoes some chemical transformations within first 24 hours. These transformations make a positive effect on water quality. For the retention times longer than 48 hours, grey water dissolved oxygen level drops [15]. For this reason, it is important to arrange retention time conveniently. In this study, retention time for grey water was taken as 24 hours. Examining the domestic re-use possibilities, 2 different scenarios were considered; first one includes storage of grey water from bathroom faucet, shower and washing machine as flushing water. In second scenario, grey water collected from dishes washer and also kitchen sink was added to toilet reservoir. Potential re-use possibilities of grey water regarding both scenarios are shown on Table 4.

Table 4. Re-use scenarios for grey water

	Washing machine effluent (lt/d)	Shower and bathtub effluent (lt/d)	Bathroom faucet (lt/d)	Kitchen sink effluent (lt/d)	Dishes washer effluent (lt/d)	Total potential (lt/d)	Flushing requirement (lt/d)	Retention time (max)
Scenario1	92.84	135.04	33.76	-	-	177.24	84.4	24 hours
Scenario2	92.84	135.04	33.76	33.76	4.22	215.22	84.4	24 hours

2.7. Optimized Water End Use Model

It is a requirement to optimize end uses to save water. There is a potential of rainwater use for domestic water end uses. Additionally, it is also possible to re-use grey water fractions in some degree. Introducing all different scenarios for rain water harvesting and grey water re-use, four different proposed scenarios with different efficiency levels are shown in Table 5.

Table 5. Proposed water use/re-use models

		1. Option	2. Option	3. Option	4. Option
Rainwater harvesting (per week)	Receiving end use	WM, DW		WM, DW IR	
	Requirement	0.69 m^3		1.00 m^3	
	Harvesting volume	1.30 m^3		1.63m^3	
	Reservoir volume	12 m^3	6 m^3	18 m^3	9 m^3
	Efficiency	100%	90%	100%	90%
Grey water re-use (per week)	End use	Toilet reservoir		Toilet reservoir	
	Grey water resources	WM, bathing-shower, bathroom faucet	WM, bathing-shower, bathroom faucet kitchen sink, dishes washer	WM, bathing-shower, bathroom faucet	WM, bathing-shower, bathroom faucet kitchen sink, dishes washer
	Requirement	0.59 m^3 (weekly total)			
	Re-use potential	1.26 m^3	1.54 m^3	1.26 m^3	1.54 m^3
	Reservoir volume	0.18 m^3	0.22 m^3	0.18 m^3	0.22 m^3
Requirements, assumptions and limitations	Rain water harvesting equipment and grey water re-use system required. Neutralization and pretreatment required for rainwater. It is assumed that grey water not contaminated with black water. It is assumed that eco friendly detergents and other cleaning materials have been used in the system.				
Potable water use (m^3)	monthly	12.66		13.86	
	annaul	154.02		166.32	
Potential (m^3) savings	monthly		5.12 (% 40)		6.36 (% 46)
	annaul		66.56 (% 43)		66.56

WM: Washing Machine, DW: Dishes washer, IR: Irrigation

3. CONCLUSIONS

Scenarios produced for grey water re-use requires indoor plumbing to be designed or retrofitted. For retention times longer than 24 hours, grey water re-use should be handled in a careful manner. Thus any selected reservoir volume for storing grey water should both be able to by-pass a certain volume of water and the volume which is stored for 24 hours. Additonally it is also requirement to prevent any leakage and odor problem.

It is possible to provide water savings between 40% and 46% on total domestic water consumption in case of a combined system installed. Although harvested rainwater seems prone to health risks, studies show that many problems are related with collection process [16]. In many cases, samples taken from harvested rain water are meeting the water quality standards [17]. For indirect human consumption applications like washing machine or clothes washer, treatment with hydrogen peroxide makes rain water biologically sterile [18]. Rain water could be used for washing machine, dishes washer and greenhouse or garden irrigation, via application of neutralization and also disinfection [19].

Proposed water use model requires an extra indoor plumbing line in addition to potable water and waste water lines. Consideration in the design level and application of this additional equipment for rain water harvesting and grey water reuse could deliver chance for saving potable water and lead to mitigate financial burdens of redundant potable water use.

Acknowledgments

First author wishes to express thanks to Professor Cumali Kınacı, General Director of Water Management of Turkey, for his kind support to get access to required data from related public authority.

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