EFFECT OF DRY PERIOD ON SIZING OF DOMESTIC RAINWATER HARVESTING TANK

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ABSTRACT

Rainwater harvesting is widespread throughout the world as a sustainable water management practice. In this work, the effect of dry period length on sizing of rainwater harvesting tank for domestic use is studied for 75 stations of Greece. The size of rainwater harvesting tanks was determined using a daily water balance method to meet non-potable water demand taking into account, among others parameters, the daily rainfall data, the family size and the roof collection area. The results demonstrated that the tank size is strongly affected by the dry period length. Comparison among stations with large difference in dry period showed large difference in tank sizes, regardless of their difference in annual rainfall.

Keywords: rainwater harvesting, dry period, tank size.

1. Introduction

Rainwater harvesting, as an alternative water resources, can be used to address the issue of pressure on water resources (EEA, 2009). It is known that the rainwater harvesting, as a water management practice, is widespread throughout the world, providing potable and non-potable water for domestic use. In the case of potable water saving, several studies report that the effectiveness of rainwater harvesting systems ranged from 12% to 100% in accordance to the specific environmental conditions (Herrmann and Schmida, 1999; Sazakli *et al.*, 2007; Ghisi *et al.*, 2007; Zhang *et al.*, 2009; Abdulla and Al-Shareef, 2009)

Several methodologies have been proposed to determine the optimal size of rainwater tanks based either on daily water balance model (Fewkes 1999; Villarreal and Dixon 2005; Ghisi and Ferreira 2007; Zhou *et al*. 2010; Palla *et al*. 2011; Campisano and Modica 2012; Hajani and Rahman 2013; Tsihrintzis and Baltas 2013), or on stochastic rainfall generations (Lee *et al*. 2000; Tsubo *et al*. 2005; Guo and Baetz 2007; Cowden *et al*. 2008; Basinger *et al*. 2010; Chang *et al*. 2011; Wang and Blackmore 2012).

The capacity of rainwater harvesting tanks cannot be formulated, because it is strongly affected by various local variables, such as local rainfall, the collection surfaces, the demand and the number of served residents (Aladenola and Adeboye 2010; Eroksuz and Rahman 2010).

Palla *et al* (2012) in order to evaluate the performance of domestic rainwater harvesting systems under various European climate zones, studied 46 sites distributed among 5 main climate zones and demonstrated that the antecedent dry weather period is the main hydrologic parameter affecting the system behavior compared to the other rainfall event characteristics.

In Greece due to the unequal distribution of water resources and demand, in both space and time, rainwater harvesting was traditionally a widespread water management practice, while nowadays it is statutorily imposed the construction of rainwater harvesting tanks in 27 Aegean islands (Official Gazette of the Hellenic Republic, Fourth Issue - No 732 – July 7, 1993; Official Gazette of the Hellenic Republic, Fourth Issue - No 402 – May 17, 2002).

The aim of this study is the investigation of dry weather period effect on the sizing of domestic rainwater harvesting tanks in Greece. For this purpose, 75 sites distributed all over Greece were selected to determine the size of domestic rainwater harvesting tank using a daily water balance method. The capacity of rainwater harvesting tank were calculated to meet 30% of non-potable water demand of a household of 4 residents taking into account a roof collection area 200 m^2.

2. Methodology

2.1. Study areas

Based on DIN 1989-1 (2002) which recommends that the daily rainfall record, of at least 5-10 years, for the area where the rainwater harvesting tank will be located, is needed, 75 stations distributed all over Greece were selected taking into account the spatial rainfall variability (Table 1). The daily rainfall data were obtained from the Ministry of the Environment, Energy and Climate Change (http://kyy.hydroscope.gr) regarding the time period 1980-1996.

2.2. Daily water balance model

A daily water balance model (Tsihrintzis and Baltas, 2013) was developed for the sizing of rainwater harvesting tank:

$$S_t = S_{t-1} + R_t - D_t \qquad 0 \le S_{t-1} \le V_{tank} \tag{1}$$

where S_t is the stored volume at the end of t^{th} day (m^3), S_{t-1} the stored volume at the beginning of t^{th} day (m^3), R_t the harvested rainwater volume during the t^{th} day (m^3), D_t the daily water demand (m^3) and V_{tank} the capacity of rainwater tank (m^3).

The daily harvested rainwater volume (runoff), R_t (m^3), is calculated as

$$R_t = C \cdot A \cdot P_{eff,t} \tag{2}$$

where C *is* the runoff coefficient, A is the rainfall collection area (m^2), and $P_{eff,t}$ is the daily effective rainfall depth at the end of t^{th} day (m). In this study, the runoff coefficient was assumed equal to 0.9 and the roof area was selected equal to 200 m^2 which represents an achievable overall collection area within suburban and rural areas. The daily effective rainfall was assumed equal to the daily rainfall minus a first flush equal to 0.33 mm (Yaziz *et al.*, 1989) for improving the quality of harvested rainwater from concentrations of dust, leaves and bird droppings in rainfall collection area.

The daily water demand, D_t, of a household is calculated as

$$D_t = N_{cap} \cdot q \cdot \left(p/100 \right) \tag{3}$$

where N_{cap} is the number of capita (residents), q is the daily water use per capita, and p is the percentage of total water demand satisfied by harvested rainwater.

In this study, the water demand for non-potable use of a typical Greek household with a number of capita N_{cap}=4 was determined, assuming q=150 L/cap/day and p=30% i.e. 45 L/capita/day. This percentage correspond to water use for toilet flushing (~30%), bathroom-shower (20%-30%) and/or cloth and dish washing (~15%).

Taking into account Eqs. (1) to (3), the daily rainwater stored volume is calculated as

$$S_t = S_{t-1} + C \cdot A \cdot P_{eff,t} - N_{cap} \cdot q \cdot \left(p/100 \right) \tag{4}$$

Assuming the capacity of the rainwater tank, the daily stored water in the tank was calculated using heuristic algorithms iteratively, allowing the excess water to overflow and when the stored water is inadequate to meet the demand, then the water needed is covered from the public water supply.

In this study, following the above mentioned methodology and assuming reliability 100% of the rainwater harvesting system i.e. meeting 30% of non-potable water demands of a household of 4 residents for zero public water supply, the optimal size of rainwater harvesting tank was determined.

3. Results

In Table 1, the mean annual rainfall values (P) and the corresponding standard deviation values (σ_P) for the rainfall time series of 75 rainfall stations used are given. As shown, P values ranged from 323.0 to 1405.2 mm, representing the climate variety of Greece: from dry regions in the rain shadow of Pindos range, to mountainous areas of this range which are affected by weather systems coming from the west causing orographic rains. Also, in the same table, the mean values of the longest annual dry periods (N_{dd}) recorded and the corresponding standard deviation values (σ_{Ndd}) for the rainfall time series of all stations studied are given. The N_{dd} values ranged from 34.0 to 160.7 days, also representing different climate types of Greece: mountain inland areas with often summer storms on one hand and sunny Aegean islands with rare summer rains, on the other.

According to the above mentioned climatic and hydrological variety of Greece, the required rainwater tank volumes (V_{tank}) ranged broadly, from 14.6 m^3 in Agnanta (Arta), where the lower N_{dd} and second higher P values observed, to 130.4 m^3 in Markopoulo (Attica), where both high N_{dd} and low P values observed (Table 1).

As given in Table 1 and illustrated in Figure 1a,b, in approximately 90% of the stations studied, a 50 m^3 tank volume can provide the water needed for a typical family (4 capita) bathroom use (45 l/cap/day).

In order to investigate the effects of both dry period length and rainfall depth on rainwater tank sizing, the regression curves between V_{tank} and both P and N_{dd} are depicted in Figure 1a-f. In Figure 1a,b the regression curves concerning all stations studied are depicted. For better evaluation of the results, the regression curves for stations with P<600 mm (Figure 1c,d) and P>600 mm (Figure 1e,f) are also depicted. As shown from the correlation coefficient of Pearson r (Figure 1a-f), generally there is a medium to strong linear correlation between V_{tank} and both P and N_{dd} ($0.41<r<0.76$). Moreover, the slopes of V_{tank} vs N_{dd} regression curves (Figure 1b,d,f) are remarkably greater than those of V_{tank} vs P (Figure 1a,c,e), which corresponds to a much stronger effect of N_{dd} in V_{tank} size than the effect of P.

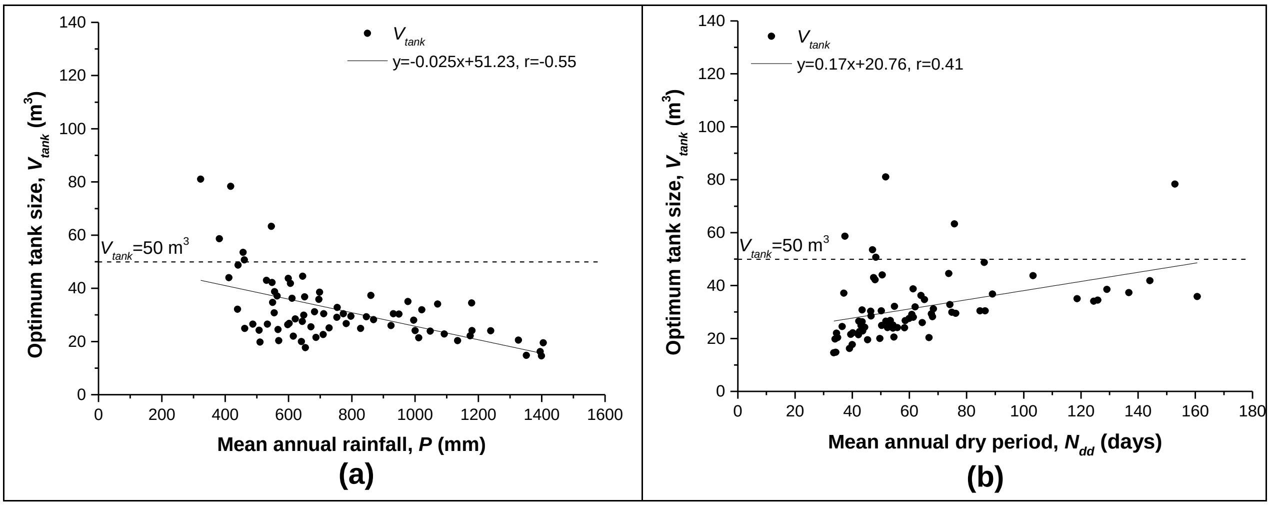
Overall, regression analysis showed that the dry period length has a much more dominant role in rainwater tank sizing than annual rainfall depth and that in general, tank sizes become larger as the dry period increases.

Table 1: Required rainwater tank volumes to meet 30% of total daily unit water demand 150 L/cap/day for 4 residents and roof area 200 m^2 for zero public water supply (i.e. 180 L/day). Mean annual rainfall (P) and mean values of the longest annual dry periods (N_{dd}), and the corresponding standard deviation values (σ_P, σ_{Ndd}), respectively, for the rainfall time series of 75 stations studied. Rainfall time series length used was 16 years for all stations studied except the stations[1,2,3] ([1]11 years, [2]10 years, [3]7 years).

Water District	Rainfall station	Prefecture	P (mm)	σ_P (mm)	N_{dd} (days)	σ_{Ndd} (days)	V_{tank} (m^3)
Western Peloponnesus (1)	Strefio	Ilia	931.4	248.0	84.7	38.1	30.4
	Analipsi	Messinia	754.3	187.2	74.2	34.5	32.8
	Karytaina	Arkadia	846.4	210.1	67.7	23.5	29.3
	Ano Lousoi	Achaia	782.7	192.2	58.6	30.2	26.7

Northern Peloponnesus (2)	Portes	Achaia	797.5	176.1	76.2	34.0	29.5
	Asteri	Achaia	599.9	133.3	103.3	48.3	43.7
	Drosato	Achaia	753.0	147.8	60.9	24.4	29.1
	Aigio	Achaia	648.7	133.4	74.9	31.3	29.9
	Kastania	Korinthia	1000.5	180.8	55.8	30.8	24.1
	Leontio	Korinthia	645.2	207.7	73.8	39.1	44.5
	Nemea	Korinthia	611.8	138.9	64.1	29.1	36.2
	Spathovouni	Korinthia	441.2	110.5	86.2	34.9	48.7
Eastern Peloponnesus (3)	Kandila	Arkadia	828.3	183. 8	50.3	17.5	24.9
	Nestani	Arkadia	602.7	160.2	53.3	29.1	26.8
	Neochorio	Argolida	711.9	162.8	50.2	25.5	30.4
	Vrontamas	Lakonia	546.5	143.2	75.8	33.9	63.3
Western Sterea (4)	Agios Nikolaos	Aito/Ania	868.8	211.7	68.1	20.0	28.2
	Poros Riganiou	Aito/Ania	1180.0	243.2	52.4	21.0	24.1
	Grammeni Oxia	Aito/Ania	949.4	178. 7	46.5	22.4	30.3
	Karpenisi	Evritania	1011.8	239.6	42.2	19.1	21.4
	Pyra	Fokida	1174.4	192.2	40.2	18.4	22.1
Epirus (5)	Filiates	Thesprotia	1134.5	184.7	66.9	21.3	20.3
	Paramythia	Thesprotia	1395.3	234.1	39.1	15.2	16.2
	Vasiliko	Ioannina	1092.2	154.2	43.7	18.2	22.8
	Grevenitio	Ioannina	1351.7	217.5	34.3	9.9	14.8
	Kanalaki	Preveza	1048.3	183.4	54.3	23.2	23.9
	Louros	Preveza	1239.0	287.0	58.3	18.7	24.0
	Aneza	Arta	924.1	201.4	64.5	21.0	26.0
	Kato Kalentini	Arta	1326.6	266.4	54.6	23.5	20.5
	Agnanta	Arta	1399.4	244.7	33.6	8.3	14.6
Attica (6)	Markopoulo	Attica	419.1	153.1	126.7	35.5	130.4
Eastern Sterea (7)	Kaloskopi	Fokida	682.6	273.7	68.4	26.2	31.2
	Drymaia	Fthiotida	644.0	160.0	59.9	30.7	27.5
	Elatia	Fthiotida	550.4	147.6	65.3	29.0	34.7
	Atalanti	Fthiotida	556.3	149.3	61.3	22.4	38.7
	Davleia	Viotia	773.5	158.2	86.5	39.3	30.4
	Agia Triada	Viotia	995.6	193.3	61.4	19.2	28.0
	Prokopion	Evia	1021.2	328.1	62.0	20.4	31.9
	Almyropotamos	Evia	651.3	158.5	89.1	28.2	36.8
Thessaly (8)	Elati	Trikala	1405.2	322.0	45.4	15.3	19.5
	Farkadona	Trikala	533.5	103.4	51.8	18.2	26.5
	Anavra	Karditsa	728.5	192.4	54.2	21.4	25.1
	Karditsa	Karditsa	548.4	168.1	48.0	19.0	42.2
	Zappeio	Larisa	439.6	98.3	54.8	22.3	32.1
	Spilia	Larisa	671.0	197.1	52.9	24.4	25.5
Western Macedonia (9)	Koula Prespon[1]	Florina	510.3	90.3	34.0	11.1	19.8
	Kastoria[1]	Kastoria	569.6	115.2	34.9	13.2	20.3
	Siatista	Kozani	653.5	82.3	40.0	14.4	17.7
	Kastania[1]	Imathia	567.2	159.6	36.5	11.5	24.5

	Katerini	Pieria	555.1	139.9	43.5	13.5	30.8
Central Macedonia (10)	Paralimni Giannitson[2]	Pella	461.1	133.6	48.3	16.5	50.7
	Evzonoi[2]	Kilkis	462.3	115.4	43.1	9.0	24.9
	Polykastro[2]	Kilkis	507.6	119.1	44.4	10.7	24.2
	Arnea[2]	Chalkidiki	598.1	168.7	43.5	19.3	26.3
Eastern Macedonia (11)	Fragma Kerkinis	Serres	323.0	69.4	51.7	21.2	81.0
	Nigrita	Serres	412.0	84.3	50.5	23.8	44.0
	Alistrati	Serres	615.7	124.7	34.5	8.2	22.0
	Drama	Drama	382.0	101.4	37.5	9.2	58.6
Thrace (12)	Mikrokleisoura	Drama	710.1	205.0	42.6	19.8	22.6
	Paranesti	Drama	530.8	160.9	47.5	20.3	43.0
	Chrysoupoli	Kavala	487.5	104.9	42.3	13.9	26.5
	Toxotes	Xanthi	564.4	159.3	37.1	12.4	37.1
	Kimmeria[2]	Xanthi	687.1	122.5	39.5	15.3	21.5
	Porpi	Rodopi	457.2	127.5	47.1	22.4	53.5
	Organi	Rodopi	622.0	186.5	46.6	16.3	28.5
	Lefkimi	Evros	640.9	151.3	49.7	20.7	20.0
Crete (13)	Stroviles	Chania	1071.2	302.1	124.5	38.4	34.1
	Meskla	Chania	1178.9	315.2	125.9	39.7	34.5
	Armenoi	Rethymno	977.7	223.1	118.7	29.1	35.0
	Akoumia	Rethymno	860.5	173.5	136.8	37.6	37.3
	Ano Archanes	Heraklio	698.4	180.1	129.1	34.4	38.5
	Zakros	Lasithi	606.6	155.3	144.1	42.1	41.8
Aegean Islands (14)	Faneromeni[3]	Naxos	417.6	137.8	152.9	32.2	78.3
	Karlovasi[3]	Samos	696.3	146.3	160.7	22.7	35.8
	Keramia	Lesvos	678.6	182.4	144.1	41.6	64.5



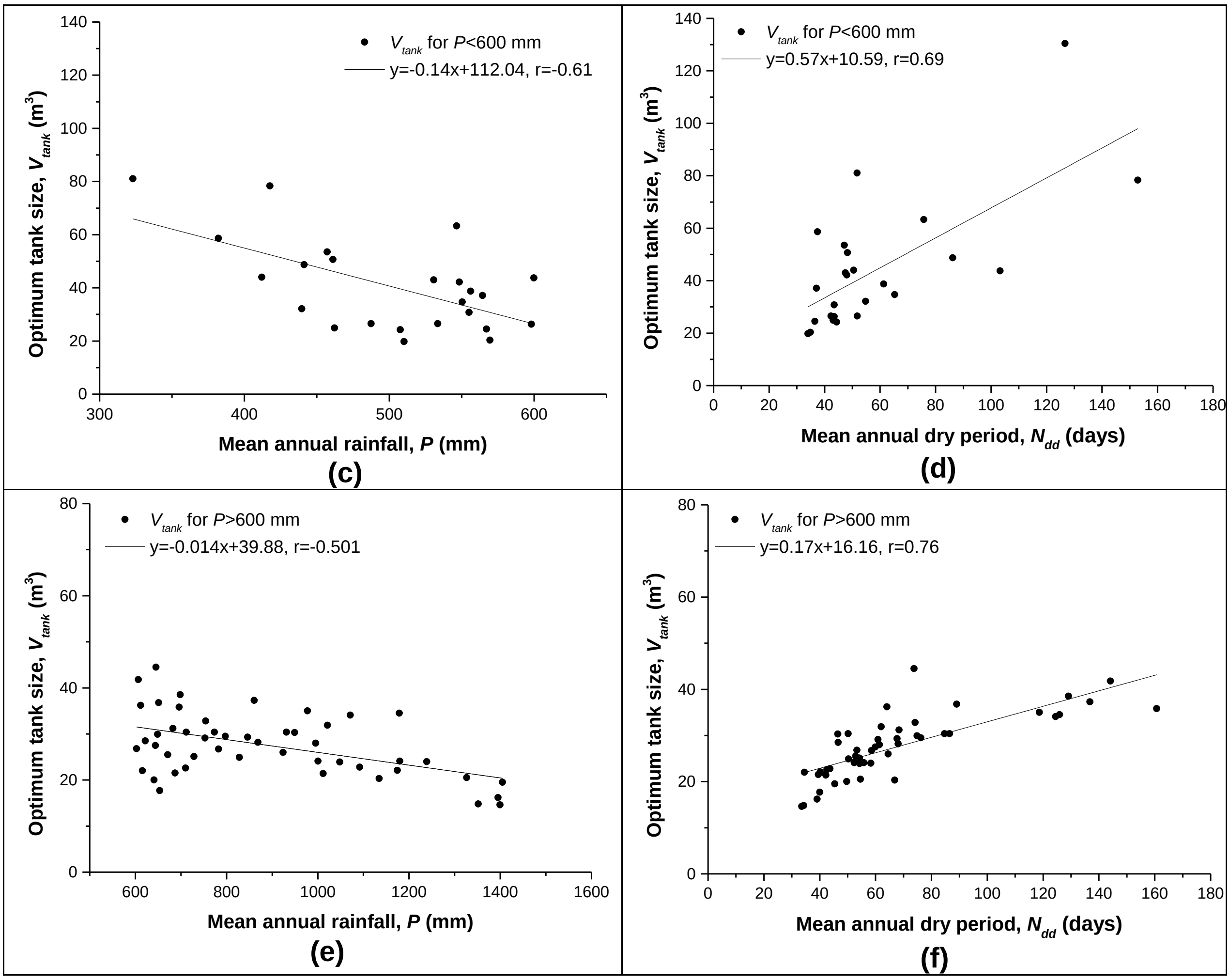


Figure 1: Regression curves between the optimum tank size (V_{tank}) and (a) mean annual rainfall (*P)* for the 75 stations studied, (b) mean annual dry period (N_{dd}) for the 75 stations studied, (c) mean annual rainfall for stations studied with *P*<600 mm, (d) mean annual dry period for stations studied with *P*<600 mm, (e) mean annual rainfall for stations studied with *P*>600 mm and (f) mean annual dry period for stations studied with *P*>600 mm.

4. Conclusions

Greece has a variety of climate types, which corresponds to great spatial rainfall and dry period variability. Dry period length rather than annual rainfall, has the dominant role in tank sizing, resulting in large differences in tank sizes among stations with large difference in dry period, practically regardless their difference in annual rainfall.

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