Rainwater harvesting for home-garden irrigation: a case study in Italy

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Rainwater harvesting for home-garden irrigation: a case study in Italy

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In residential buildings, drinking water is often used for tasks that do not necessarily require high quality water, such as home-garden irrigation. Our research focuses on the idea of harvesting rainwater to promote sustainable management of low-quality water resources on a building scale for irrigation purposes. The effectiveness of a collection system depends on the weather conditions, which determine also the water need of the plants, on the size of the cultivated area and on the collection surfaces. In this research, a rainwater harvesting system (RWH) for the irrigation of home-gardens in the city of Celano (L'Aquila – Italy) has been analysed. The obtained results show that to maximize water savings a great investment is necessary, i.e. not refundable in a reasonable period due to the low cost of drinking water. On the contrary, to maximize the economic return, it is required a smaller and cheaper tank, but the maximum water savings efficiency decrease to about 60%. In the latter case the RWH system can be cheaper than an irrigation plant supplied by the aqueduct. In the work graphs are provided for practical design use for realizing a RWH system in areas with meteorological conditions similar to those of the survey area, according both the highest water savings efficiency or the highest economic return.

***Keywords**: drinking water, home-garden, sustainable management, harvesting rainwater.*

***Recupero dell'acqua piovana e irrigazione dei giardini privati: un caso studio in Italia.** Al giorno d'oggi negli edifici residenziali l'acqua potabile viene ancora impiegata per mansioni che non richiedono acqua di elevata qualità, come ad esempio l'irrigazione del giardino. Questo studio è basato sull'idea della raccolta d'acqua piovana con lo scopo di promuovere la gestione sostenibile di acqua di bassa qualità a scala di edificio ad esempio per l'irrigazione del verde privato. L'efficienza del sistema di raccolta dipende dalle condizioni meteorologiche, che influenzano anche il fabbisogno idrico delle piante, dalle dimensioni dell'area coltivata e dalla superficie di raccolta. In questo lavoro di ricerca sono stati analizzati sistemi di raccolta dell'acqua piovana per l'irrigazione di giardini nella città di Celano (L'Aquila – Italy) garantendo la continuità del verde urbano presente nella città. I risultati ottenuti mostrano, in termini economici, che per massimizzare il risparmio di acqua, anche con un'efficienza del 100%, è necessario sostenere alti costi che non possono essere ripagati in un ragionevole periodo di tempo a causa del basso costo dell'acqua potabile, mentre per massimizzare il ritorno sull'investimento si devono installare serbatoi più piccoli poiché più economici, ma il valore massimo di efficienza nel risparmio d'acqua diminuisce fino al 60%: in questo caso, per alcune combinazioni di area del tetto e del giardino, la scelta del sistema di raccolta dell'acqua piovana è più conveniente rispetto all'irrigazione basata sulla sola fornitura dell'acquedotto. Nel presente lavoro sono presentati dei grafici di uso pratico per la progettazione di sistemi di raccolta dell'acqua piovana, in zone con un clima simile a quello del sito di studio, scegliendo di massimizzare il risparmio d'acqua potabile o il ritorno sull'investimento.*

***Parole chiave**: acqua potabile, verde privato, gestione sostenibile, recupero acqua piovana.*

1. Introduction

In almost all the houses, drinking water, taken from the aqueduct, is used for internal and external uses. Among these, it is included garden irrigation, an activity for which it is possible to use non-potable water, saving drinking water for its real purpose (Conte, 2008; Palla *et al.*, 2011; Lucìo *et al.*, 2020).

For this reason, it is born the idea of mitigating the consumption of drinking water for the maintenance of private greeneries using rainwater collected by a Rainwater Harvesting System (RWH). In this system the water is collected from the roof of the building and stored in underground tanks, from which water can be withdrawn for the irrigation. This practice can have also the important effect of reducing the water volume in the sewage system and preventing the damages caused by the crisis of the sewage system during big storms, especially in urban environment. Nevertheless, the realization costs of a domestic RWH system (namely, price of tank and its accessories) are generally higher than the benefit due to the annual savings in the water bill and this is a problem that can limits the diffusion of this good practice (Campisano, 2017a). The present study shows the role of the different variables for a correct choice of the tank size.

In this paper it is reported a general method for the analysis and design of a RWH system with a case study in the city of Celano (L'Aquila – Italy). Specifically, the method is based on a water balance equation on a daily scale, where the water volume present in the tank is linked to the volume of the previous day: the main input/output are the daily meteoric inflow and the daily water demand of the cultivated area, respectively.

The aim is to provide the reader with a valid decision support tool for the implementation of the

RWH system, addressing both the economic and the environmental aspect. In order to pursue this aim, the proposed method starts from section 2, where are reported well-known methods for modelling the RWH system and for the estimation of the water demand of a cultivated surface; then, in section 3, it is presented an approach for the choice of the tank based on both water savings and economic viability of the system.

In section 4 the application of the method to gardens located in the town of Celano is shown. The results, that consist in a series of graphs, are both a resume for the case study area and a practical tool for the reader to design a RWH system also in different geographical zones but with similar climatic conditions.

2. Mathematical model

The analysis of the behaviour of a building-scale rainwater harvesting system, for maintenance of private greenery, requires the knowledge of many elements. Figure 1 represents a sketch to understand the functioning of a RWH system that involves different quantities: (1) geometric quantities like the harvesting surface H, the cultivated surface C and the tank capacity S, and (2) time dependent quantities like the rainfall P_t, the inflow volume q_t, the stored volume V_t, the rainwater supply Y_t, the water demand d_t, the drinking water supply M_t and the overflow O_t. In this work, a combination of H and C is defined *host system*.

In order to explore the performance of the system, a mathematical model simulates the mass balance equation for the tank at the daily scale. The input data are the meteorological data of the rainfall historical series. These meteorological series have a length of T days: this period, that for an accurate climatic description of the site should be at least 30 years long, should contain an integer number of years to permit the cost calculations, based on the annual price of water. With reference to the symbols in Figure 1, the mass balance equation for the tank can be written as

$$V_t = q_t + V_{t-1} - Y_t - O_t \qquad (1)$$

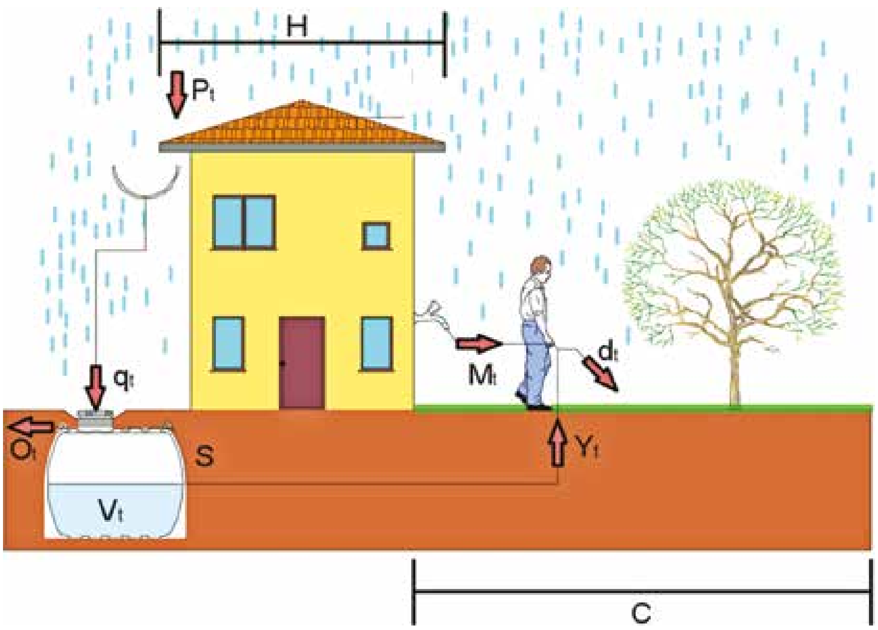

Fig. 1 – Configuration of the rainwater harvesting system.

where subscript t is related to the *t-th* day of the period T. The terms of the mass balance are evaluated using the *Yield After Spill* (YAS) rules (Palla *et al.*, 2011; Jing *et al.*, 2018):

$$Y_t = MIN\{d_t \,;\, V_{t-1}\} \qquad (2a)$$

$$V_t = MIN\{q_t + V_{t-1} - Y_t \,;\, S - Y_t\} \qquad (2b)$$

The first day of simulation the tank is considered empty, i.e $V_0 = 0$ (Palla *et al.*, 2011; UNI, 2012). According to Figure 1, in this study it is supposed that the area occupied by the tank does not reduce the cultivated area and the amount of water lost for evaporation from the tank can be neglected. The surface H is assumed to be equal to the horizontal projection of the roof, which is supposed to be made of waterproof material with a slope < 3% and a runoff coefficient ϕ = 0.8 [–] (Farreny *et al.*, 2011; UNI, 2012).

The daily flow of rainwater collected from the rooftop q_t [m^3/day] is linked to the harvesting surface H [m^2], to the rainfall height P_t [m^3/(m^2•day)] and to the runoff coefficient ϕ [–] (Palla *et al.*, 2011)

$$q_t = \phi \cdot p_t \cdot H \qquad (3)$$

The daily volume of water necessary for irrigating the C area, can be computed as the sum of the single demand of the n crops growing in the cultivated surface. The demand due to a crop is the product of the area occupied by the *i-th* crop C^i and the volume of water demand per unit area v_t^i [m^3/ (m^2•day)]. The water demand v_t^i can be estimated as

$$v_t^i = ETE_t^i - P_{n,t} \qquad (4)$$

where ETE_t^i [m^3/ (m^2 · day)] is the effective evapotranspiration of the *i-th* crop on the *t-th* day and $P_{n,t}$ is the daily net infiltration, i.e. the volume of daily rainfall that infiltrates in the ground and reaches plant roots. Daily net infiltration has been computed according to FAO indication (Doorenbos and Pruitt, 1977), while ETE_t^i has been calculated as

$$ETE_t^i = EV_t \cdot K_p \cdot K_{c,t}^i \qquad (5)$$

where $K^i_{c,t}$ [-] is the crop coefficient, K_p [-] is the pan coefficient and EV_t is the evaporation. In particular the evaporation has been calculated through the formula of Tombesi-Lauciani (Giannini and Bagnoni, 2000):

$$EV_t = a \cdot F \cdot (T_{m,t})^{0.9} \cdot 10^{-0.008 \cdot u_{m,t}} \qquad (6)$$

where a [-] is an environmental constant function of the geographic position and of the period of the year, F [-] is the Thorntwaite factor, $T_{m,t}$ [°C] and $u_{m,t}$ [%] are the mean daily temperature and the relative humidity value, respectively. Equation (6) is valid only for $T_{m,t} \geq 0$, while when the temperature is negative EV_t is clearly equal to zero. According to Allen *et al.* (1998) $K^i_{c,t}$ depends on the cultivar and its phenological phase, while K_p = 0.8 (Giannini and Bagnoni,2000). After computing the water demand for each crop, daily water demand from the whole garden can be computed, i.e.

$$d_t = \sum_{i=1}^{n} v_t^i \cdot C^i \qquad (7)$$

where C^i is the area occupied by the *i-th* crop.

3. Best tank capacities

In order to choose the tank size, different aspects should be considered. In fact, the highest reduction of drinking water consumption (environmental criterion) would lead to install a very big and expensive tank, that could not be refunded in a reasonable time period by the money saved through the reduced consumption of drinking water supplied by the aqueduct. For this reason, the economic viability of a RWH system (economic criterion) has to be also considered (Kim *et al.*, 2021). These approaches can be stated as two design criteria for the tank size, i.e. (1) maximum water savings efficiency and (2) maximum economic benefit. Through the first criterion the highest reduction of water consumption is required, while through the second criterion the highest money benefit respect the initial investment within an established period of time is pursued.

The two criteria give clearly two different tank capacities for each host system. The analysis is carried out on the results of the repetition of the mass balance equation shown in section 2 for different tank capacities S. In the following the elements used for the analysis are described.

3.1 Environmental criterion

The efficiency W_s is an index of the water savings and it is calculated as the ratio between the total rainwater volume supplied in the reference period T and the total water demand in the same period (Palla *et al.*, 2011) and it shows how much drinking water can be replaced by the harvested rainwater. Its mathematical expression is

$$W_s = \sum_{t=1}^{T} Y_t \Big/ \sum_{t=1}^{T} d_t = V_r / D \qquad (8)$$

Since the water demand (denominator) is not influenced by the tank capacity and the rainwater volume supply (numerator) grows with the tank size up to a maximum value, the idea is to choose the optimal tank looking for which tank size makes the numerator close to its maximum value: in practical case the numerator is not maximized, because further increases of the tank size, when the tank is large, result in negligible water saving increments.

3.2 Economic criterion

This criterion is based on an economic comparison between the irrigation plant based on RWH system and the same irrigation plant supplied by the aqueduct, taking into account the future growth of water price and the *discount rate* of the money, r_d. The sum of the *present value* of future annual costs is computed for both the aqueduct-based plant and the RWH-based one and then the difference between the two results, called *Net Present Value (NPV)* is computed. For the RWH-based plant it has to be also considered the initial cost (C_i). The *NPV* is computed for the whole period of the expected system life U_L [years].

The building cost C_b of the RWH system comprehends the tank price as well as pump and installation cost (namely, the excavation) and it could be expressed as a linear function of excavation volume V_e,

$$C_b = e \cdot V_e + f \qquad (9)$$

where the two coefficients e and f depend on local economic condition. Instead, the costs distributed along the system life comprehend the cost of energy consumed by the pump and the cost of drinking water C_w that has to be bought from the aqueduct in case of rainwater lack (i.e., empty tank). The pumping cost can be considered as a fraction (pp) of the initial cost C_b (see Section 4), so that it becomes dependent on the system size, thus

$$C_i = C_b \cdot (1 + pp) \qquad (10)$$

The annual cost per unit volume k_y of water from the aqueduct usually depends on the yearly volume of consumed water. This study focuses only on the annual volume of drinking water used for irrigation purpose M_y, where y indicates a generic year of the system life U_L. In the case of aqueduct-based plant, all the water demand D_y is supplied by the waterworks, so $M_y = D_y$. Thus, present values of the annual cost can be expressed, both in presence of a RWH system (subscript RWH) and in absence of it (subscript AQD) as

$$C_{w,RWH,y} = M_y \cdot k_y/(1 + r_d)^{y-1} \quad (11a)$$

$$C_{w,AQD,y} = D_y \cdot k_y/(1 + r_d)^{y-1} \quad (11b)$$

Defined the above-mentioned quantities, the computation of the economic return *NPV* (*Net Positive Value*) is given by

$$NPV = \frac{U_L}{N} \cdot \sum_{y=1}^{N} C_{w,AQD,y} + -\left(\frac{U_L}{N} \cdot \sum_{y=1}^{N} C_{w,RWH,y} + C_i\right) \quad (12)$$

where N is the length of the meteorological data series, expressed in years. The value of *NPV* is a function of the tank capacity S and the best tank size maximizes *NPV*. However, *NPV* could be positive, negative or null: if the result is positive, it means that the RWH plant is cheaper than the aqueduct-based plant and the value is the money savings in a period equal to U_L; instead, if *NPV* is negative, the RWH system is more expensive than the aqueduct-based in the U_L period. Finally, if *NPV* is zero, there is no money difference between the two plants. Nevertheless, it has to be remembered that all RWH systems always produce a water saving, although it can be not economically viable.

4. Case study

The case study considers home-gardens in the town of Celano (L'Aquila), located on the central Apennines at 800 m a.s.l, (42°05'03.5''N, 13°32'51.9''E). In Figure 2 meteorological information is given, i.e., monthly average temperature and monthly rainfall height. The mean annual rainfall is about 860 mm.

The meteorological data are referred to the twenty-nine years period 1951-1979. In particular, the temperature data are measured in Goriano Sicoli station, while rainfall height is measured in San Pelino station, both located near the study area (Regione Abruzzo, 2020). Table 1 shows the values of parameter *a* and *F* (see Section 2) for the case study.

Referring to the Figure 1, the cultivated area *C* has been designed according to a national regulation law (MATTM, 2020) that concerns green areas. The regulation law requires that the green areas should be constituted by native crops. For this reason, two green models, widespread in the study area, have been adopted. The first model (M1) is a vegetable garden with five different crops: carrots, potatoes, eggplants, tomatoes and lettuce. Each crop occupies an area of one fifth of *C*. The second model (M2) is constituted by fescue meadow and fruit trees (i.e., apple, pear and apricot), having a trunk diameter equal to 30 cm and a foliage diameter equal to 3 meters. Based on these values, the pertinence land area of a tree has been determined, that is 20 m^2 of cultivated area and so the number of trees contained in each *host system* has been calculated. In M2 the meadow occupies the whole cultivated area except the trunks area, while for trees a surface occupied by roots equal to the

Tab. 1 – Values of the constants a and F in the survey area.

Month	*a* [-]	*F* [-]
January	0.68	0.81
February	0.95	0.82
March	1.23	1.02
April	1.33	1.125
May	1.14	1.265
June	1.11	1.285
July	1	1.295
August	0.98	1.2
September	1	1.04
October	1	0.95
November	0.84	0.805
December	0.75	0.765

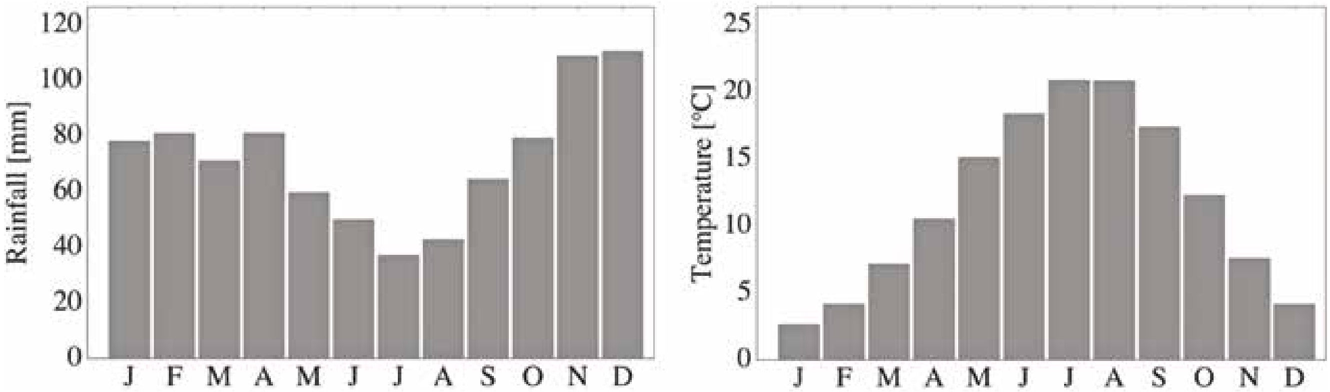

Fig. 2 – Monthly rainfall height (left) and monthly average temperature (right).

Tab. 2 – Crop coefficients for each phenological phase.

Crop	Initial	Intermediate	final
Carrots	0.7	1.05	0.95
Lettuce	0.7	1	0.95
Eggplant	0.6	1.05	0.9
Tomatoes	0.6	1.05	0.8
Potatoes	0.5	1.15	0.75
Fruit tree	0.5	1	0.8
Fescue meadow	1.05	1.1	1.1

projection of the foliage area to the ground has been considered.

The values of the crop coefficients $K^i_{c,t}$ for each crop present in the models and their phenological phase (initial, intermediate and final) are shown in Table 2. The temporal evolution of each phase (not reported) has been defined thanks to the support of some farmers of the survey area.

After analysing the temporal trend of the drinking water price in Celano, it was supposed that the cost per cubic meter of water k_y [€/m^3] will rise by 0.05 € per year in the future, starting from the actual cost (Tab. 3) defined by the water utility of the study area (CAM, 2020).

Tab. 3 – Water tariff in the study area.

Yearly consumption M_y [m^3]	k_y [€/m^3]
0-60	1.97
61-180	2.23
>180	3.12

The cost of the RWH system is based on commercial available tanks and it is composed of different parts, i.e., (1) tank price, (2) cost of excavation, (Regione Abruzzo, 2020) and (3) price of pump, filters, pipes and accessories. As a consequence, the coefficients of equation (9) can be estimated as e = 206.37 €/m^3 and f = 1462.1 €. The energy cost for water pumping has been computed starting from standard Italian norms, the rainwater volume supply and the price of energy (0.25 €/kWh): in this way the coefficient of equation (10) is pp = 0.004 for model M1 and pp = 0.01 for model M2.

The expected system life U_L is 35 years and the discounting rate r_d applied to the future annual costs is posed equal to 3.5% (European Commission, 2008; Matos *et al.*, 2015; Campisano *et al.*, 2017b; Kim *et al.*, 2021).

5. Results

The analysis considers different *host systems* characterized by their H and C values. In Figure 3 the results of the tank capacities analysis are shown for both green models, i.e., the vegetable garden, M1, and the meadow with trees, M2. Graphs are represented as function of two variables, harvesting area H and cultivated area C, while the values of the tank capacities that leads to the highest water savings efficiency are represented with level curves. In Figure 4, graphs show the values of tank capacities that lead to the highest economic return, while in Figure 5 is reported the amount of the economic return. Finally, in Figure 6, water savings efficiency has been represented as a function of the ratio between H and C, for both best tank choice criteria.

Dealing with the results related to maximizing the efficiency, Figure 3 shows that values of the best tank according to environmental criterion can be very large (higher than 10 m^3), considering both their dimensions related to the garden size and their real com-

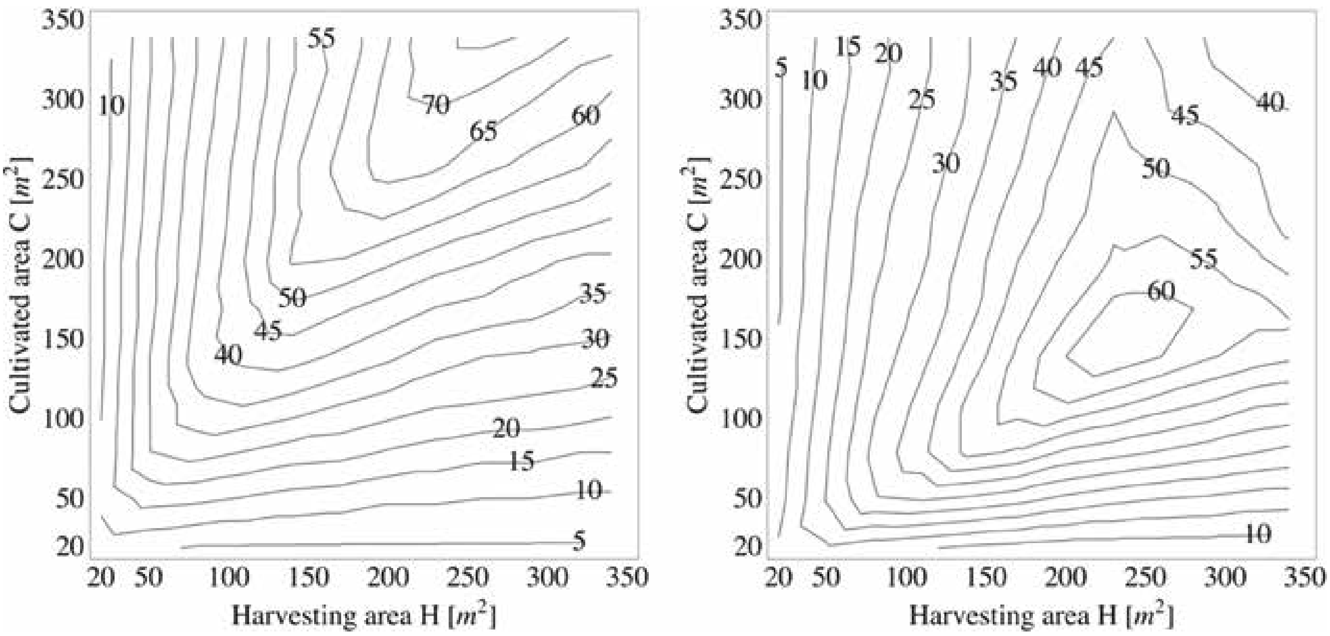

Fig. 3 – Best tank (m^3) according to the environmental criterion (highest water savings efficiency W_s): vegetable garden M1 (left) and meadow with trees M2 (right).

mercial availability. Observing the results shown in Figure 3, it can be also noticed that there is a difference between the two models due to the lower water demand of the vegetable garden than the meadow with trees. In Figure 3, two regions with different behaviour separated approximately by a line of expression *H* = *C* for model 1 and *H* = 2*C* for model 2 can be detected. In the region where *H* is bigger than *C*, for model M1 (or twice bigger than *C* for model M2) for *H* that remains constant, *S* grows with *C*, while when *C* is constant, *S* slightly decrease when *H* grows; the opposite behaviour happens in the other region. The reason of this behaviour can be understood observing Figure 6, where in former region (*H/C* > 1 for M1 or *H/C* > 2 for M2) *Ws* is approximately 1. As a consequence all the water demand can be satisfied by stored rainwater, while in the other region *Ws* is lower than 1, and so there is not enough water to satisfy the irrigation demand. Thus, in case of system with *Ws* of about 1, the greater is *C* the bigger should be the tank, instead in case of *Ws* significantly less than 1, an increase of demand (*C*) cannot be satisfied: this greater demand tends to empty the tank, and therefore a smaller tank can be sufficient.

Figure 4, instead, shows that best tanks obtained with economic criterion are generally small, being lower than 10 m^3. These tanks are usually more available on the market. It is shown that where *H* > *C* the best capacity raises with the increasing of *C*, while for *H* < *C* the best capacity raises when *H* increase.

In Figure 5 the related *NPV* in 35 years due to the choice of the best tank according to the economic criterion is shown. Two regions are present: a region (*NPV* > 0) where the RWH system is cheaper than the irrigation plant connected to the aqueduct and a region (*NPV* < 0) where the RWH system is more expensive. The line with the value zero represents the *host systems* (pair values *H* and *C*) for which the money savings due to the RWH has reached the initial cost of installation, so there is no economic difference (in 35 years) between the RWH system and the aqueduct-based system.

From Figure 5 (left) it is also possible to observe that for the most combination of *H* and *C* there is an economic loss, that is due to the low water demand and low recovered rainwater volume: this fact, together with low cost of drinking water, gives a small annual economic benefit. For this reason, only larger *host systems*, with great water demand, give a positive *NPV*. Nevertheless, the loss is not so high, in fact, considering typical initial cost for optimal tanks, about half of it can be recovered at the end of system life. For model M2 (Fig. 5 right) instead, there are more situations with positive economic return, because the water demand is higher than M1.

Finally, Figure 6 shows clearly that the choice of a tank with the economic criterion leads to a smaller water savings efficiency than the environmental criterion, although some *host system* can reach remarkable water saving values too.

6. Conclusions

In this paper a method for the design of a RWH system for private greenery irrigation is proposed: two models of greenery are stu-

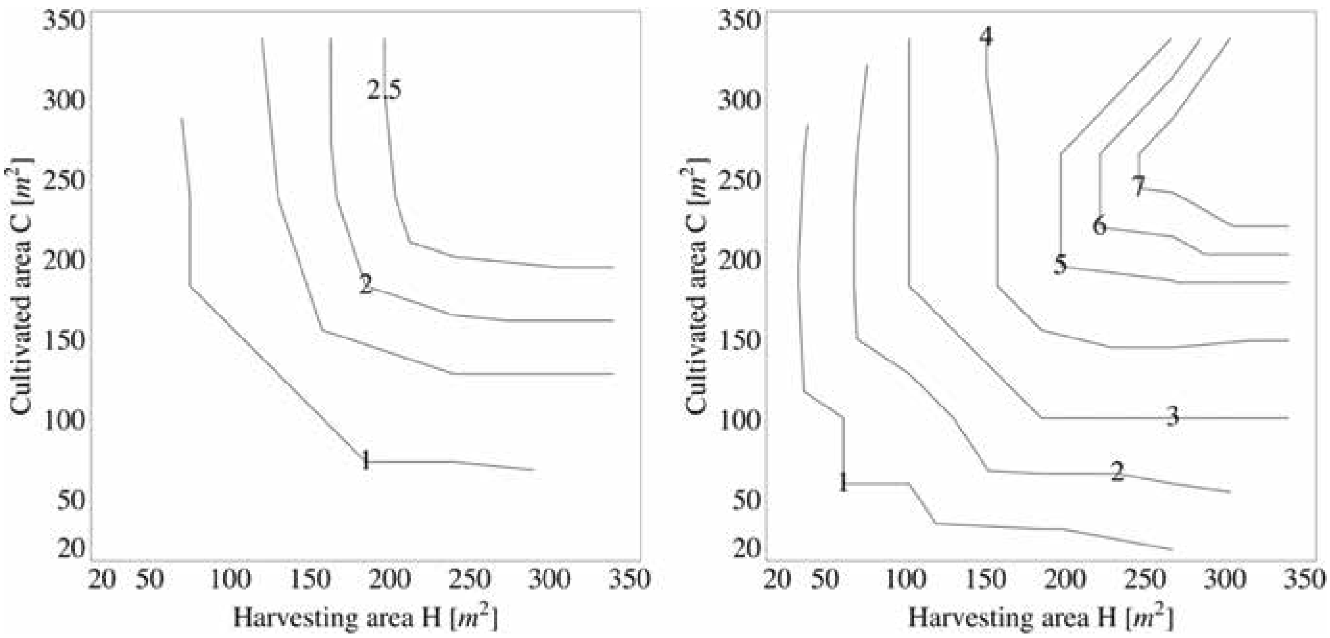

Fig. 4 – Best tank capacity (m^3) according to the economic criterion (highest Net Present Value in 35 years): vegetable garden M1 (left) and meadow with trees M2 (right).

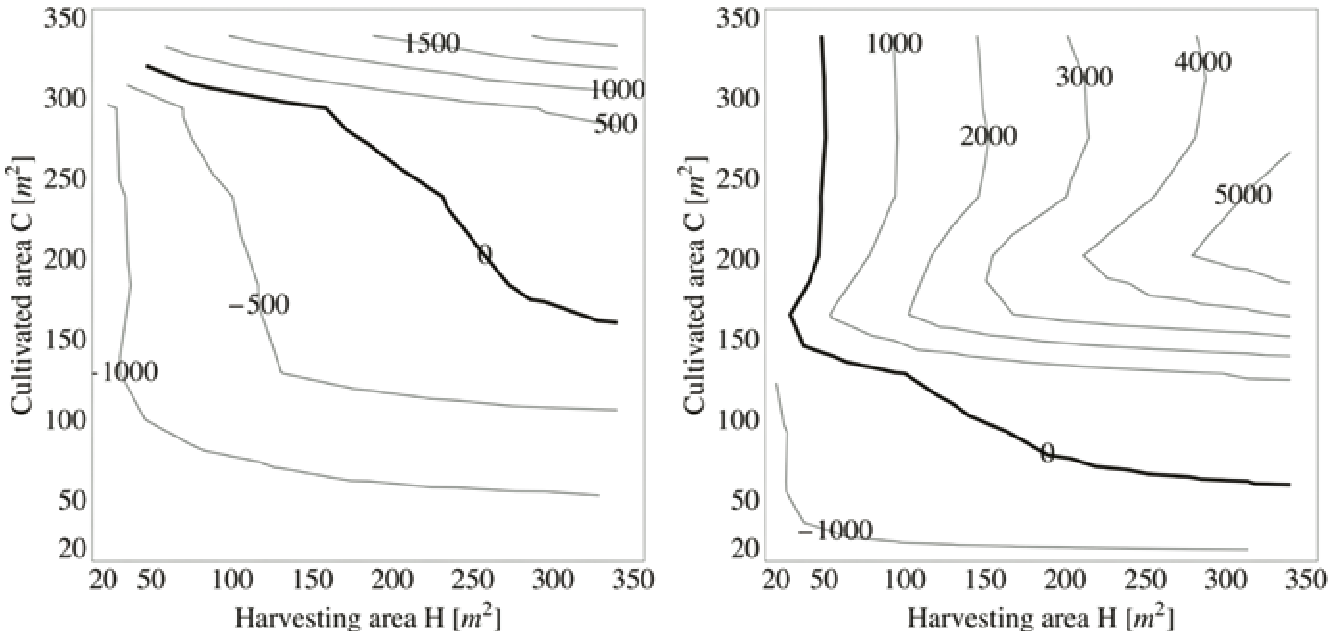

Fig. 5 – NPV (€) in 35 years of the RWH systems designed according to Figure 4: vegetable garden M1 (left) and meadow with trees M2 (right).

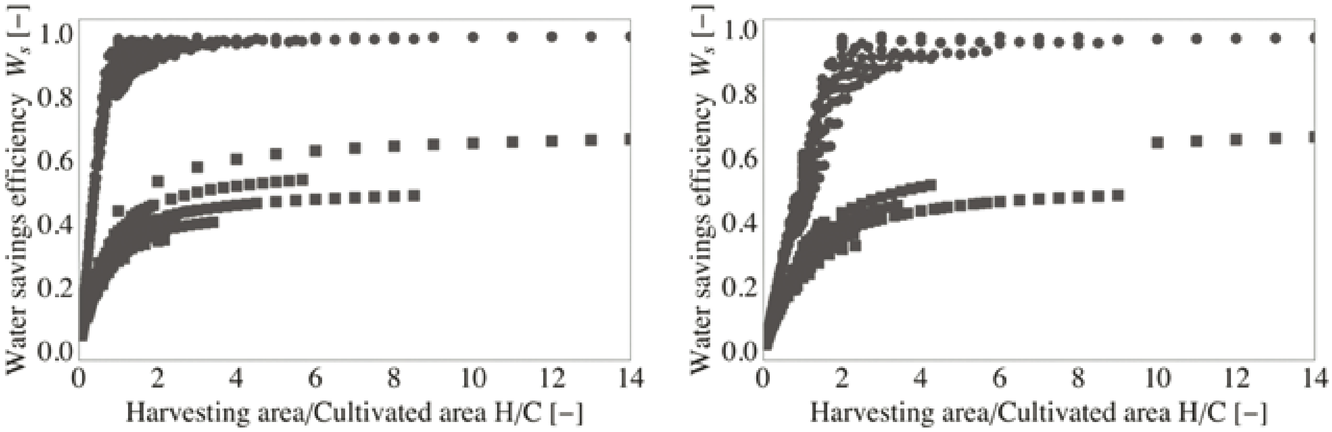

Fig. 6 – Water savings efficiency for environmental design (maximum Ws, dots) and economic design (maximum NPV, squares): vegetable garden M1 (left) and meadow with trees M2 (right).

died, a vegetable garden (M1) and a meadow with fruit trees (M2). The method is based on a daily hydraulic analysis of the water volume stored in the tank, with input the historic meteorological data and geometric data of the so-called *host system* characterized by an harvesting area *H* and a cultivated area *C*. The analysis explores the results for a series of possible capacities for the tank, both in terms of water savings efficiency and in economic terms (*Net Present Value*). The aim is to identify the best tank to install in each *host system*. Results for the case study show that there are two criteria for the choice of the tank capacity: the maximum water savings efficiency, that leads to high costs of installation, and the maximum *NPV*, that leads to lower water savings efficiency. The study has shown that RWH irrigation plant for some *host systems* can be cheaper (at the end of the system life) than aqueduct-based plant, if a good choice of the tank size is made.

The graphs shown in this work can be directly used for the design of a RWH irrigation plant also in different geographical zones but with a similar climatic conditions.

Although the green models considered are only two among the many possible, they can be considered as reference for the design of RWH system for a lot of other kinds of home-gardens, even in different geographical zones but with similar climatic conditions.

Some approximations have been done in the work, for example neglecting soil water content dynamic, but they are issues for future studies, as well as the use of a more detailed crop water requirement estimation method, especially dealing with cases characterized by more detailed meteorological data.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. *Irrigation and drainage paper No. 56, Crop evapotranspiration.* FAO, Rome.

Campisano, A., Butler, D., Ward, S., Burns, M., Friedler, E., DeBusk, K., Fisher-Jeffes, L.N., Ghisi, E., Rahman, A., Hiroaki, F., Mooyoung, H., 2017a. *Urban rainwater harvesting systems: Research, implementation and future perspectives*. Water research, vol. 115, pp. 195-209.

Campisano, A., D'Amico, G., Modica, C., 2017b. *Water Saving and Cost Analysis of Large-Scale Implementation of Domestic Rain Water Harvesting in Minor Mediterranean Islands*. Water, vol. 9.

Conte, G., 2008. *Clouds and flush toilets*, Environment editions. (Italian).

Doorenbos, J., Pruitt, W.O., 1977. *Irrigation and drainage paper No. 24, Crop water requirements.* FAO, Rome.

European Commission, Directorate General Regional Policy, 2008. *Guide to cost-benefit analysis of investment projects*.

Farreny, R., Morales-Pinzon, T., Guisasola , A., Tayà, C., Rieradevall, J., Gabarrell, X., 2011. *Roof selection for rainwater harvesting: quantity and quality assessments in Spain*. Water research, vol. 45, pp. 3245-3254.

Giannini, A., Bagnoni, V., 2000. Irrigation techniques data sheet for Tuscan agriculture. ARSIA. (Italian).

Jing, X., Zhang, S., Zhang, J., Wang, Y., Wang, Y., Yue, T., 2018. *Analysis and Modelling of Stormwater Volume Control Performance of Rainwater Harvesting Systems in Four Climatic Zones of China*. Water Resources Management, vol. 32, pp. 2649-2664.

Kim, J.E., Teh, E.X., Huemphrey, D., Hofman, J., 2021. *Optimal storage sizing for indoor arena rainwater harvesting: hydraulic simulation and economic assessment.* Journal of Environmental Management, vol. 280.

Lúcio, C., Silva, C.M., Sousa, V., 2020. *A scale-adaptive method for urban rainwater harvesting simulation.* Environmental Science and Pollution Research, vol. 27, pp. 4557-4570.

Matos, C., Bentes, I., Santos, C., Imteaz, M., Pereira, S., 2015. *Economic Analysis of a Rainwater Harvesting System in a Commercial Building.* Water Resource Management, vol. 29, pp. 3971-3986.

MATTM – Italian ministry of the environment, decree 10/3/2020. Main environmental criteria for public green areas management. (Italian).

Palla, A., Gnecco, I., Lanza, L.G., 2011. *Non-dimensional design parameters and performance assessment of rainwater harvesting systems.* Journal of Hydrology, vol. 401, pp. 65-76.

UNI/TS 11445, 2012. Rainwater harvesting systems for non-potable uses. (Italian).

Web sites

Regione Abruzzo, Idrografico mareografico, www.regioneabruzzo.it/content/idrografico-mareografico (last access 7/11/2020).

Regione Abruzzo, Nuovo prezzario regionale, www.regioneabruzzo.it/content/nuovo-prezzario-regionale (last access 9/12/2020).

CAM – Consorzio Acquedottistico Marsicano S.p.A., www.camspa.com/archivio2_aree-tematiche_0_100.html (last access 7/12/2020).