Rainwater harvesting in non-potable urban uses - A tool for evaluation of viability applied to Portugal

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Abstract

Rainwater harvesting constitutes a measure with some potential to reduce the potable water consumption in uses where water quality can have lower standard than drinking water.

However, given that a rainwater harvesting system (RWHS) requires some investment, the evaluation of the potential benefits for different storage capacities allows supporting the decision on system capacity, in each particular situation, and to study different system alternatives.

This paper aims to contribute to the promotion of rainwater harvesting in non-potable urban uses (toilet flushing, watering of gardens…) in Portugal. The main objective is the divulgation of a user friendly elaborated simulator which can be used in different installations for the analysis of the viability in domestic or collective installations, for Portuguese hydrological conditions.

In this document a synthesis of relevant aspects for the rainwater harvesting is presented, and SWOT analysis is used to elaborate a critical analysis based on the literature review. A brief description of developed simulator structure and application is also made in this paper.

The simulator can be applied in different regions of Portugal, allowing users to analyse the net benefit of applications of rainwater harvesting schemes for different storage capacities of RWHS. The user only needs to provide information on the planned uses and collection areas connected to the system.

The simulator was tested in three case studies. Results show that benefits of rainwater harvesting tend to be higher when installations have higher non-potable water consumption and collection areas.

Keywords: rainwater harvesting, RWHS, non-potable urban uses, simulator, viability

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1 Introduction

Rainwater harvesting is an old practice that was gradually abandoned in many regions as public water supply systems (WSS) were expanding. Nowadays, given the trend to value more sustainable approaches to urban water management, through re-naturalization of the urban water cycle or implementation of water conservation practices, advantages of techniques for using rainwater captured locally are increasingly recognised. In regions where water resources are not abundant, or where demand growth results in significant stress on water resources, the use of alternative water sources is recommended (Carlon, 2005).

Given the increasing quality requirements, costs of drinking water production tend to rise and utilization in uses that do not need these quality standards is seen as a considerable waste. Uses compatible with non-potable water include car washing, cleaning of pavements, toilet flushing and irrigation of plants and gardens. In public areas or facilities other uses can be considered such as street cleaning, sewer flushing or cooling processes.

Naturally, the potential for rainwater harvesting depends on local precipitation patterns (temporal and spatial distribution) and volume, on storage volume available and on collection surfaces available (roofs or other surfaces).

Nowadays, examples of rainwater harvesting systems can be found in countries such as Australia, South Africa, Japan, Germany and USA, among others, illustrating the benefits that can be obtained (Tomaz, 2003). In addition to complementing available water supply, benefits of rainwater harvesting can include reduction of runoff, and consequently of flood frequency and magnitude, reduction of sewer overflows and of inflow to sanitary systems, causing negative impacts on wastewater treatment plant (WWTP) efficiency. However, in countries like Portugal, only a few cases can be found even if significant potential exists. In fact, Portuguese climate is characterised by a marked rainfall seasonality, concentrated in the period October to May, and high temperatures in the dry season. Rainfall also has significant variations in the country, and drought in experienced in some regions particularly in summer. In this context, the capture and storage of rainwater could contribute to reduce water scarcity, pressure on water resources and reducing runoff and associated potential negative impacts.

Currently, there is no national document regulating the utilization of rainwater harvesting systems in non-potable urban uses. However, this is one of the measures (reuse or use of lower quality water) considered in National Programme for the Efficient Use of Water (PNUEA) (Baptista *et al.*, 2001), which was recently approved by Resolution of the Council of Ministers n. º 113/2005, on June 30th, 2005. According to Baptista *et al.* (2001) and Almeida *et al.* (2006), this measure is of interest in terms of the efficient use of water but its application requires appropriate technical regulation to avoid potential dangers to public health, diffusion of inefficient technology and increase availability of the suitable equipments in the national market. Rainwater harvesting for non-potable urban uses is also referred to in other measures, namely, the use of rainwater in gardens and similar and the use of rainwater in lakes and urban water features.

The PNUEA was elaborated in the sequence of the Water Framework Directive (WFD) (Directive n. º 2000/60/CE of October 23rd) transposed into national law by the Water Law (Law n. º 58/2005 of December 29th) (DQA, 2000).

Finally, the Strategic Plan for Water Supply and Wastewater Sanitation 2007 – 2013 (PEAASAR II), approved by Order nº 2339/2007 of February 14th, 2007, lists the balance of supply and demand through demand management, efficient use of water, increase of reuse and exploitation of alternative sources (rainwater, brackish groundwater, marine water and wastewater treated) as one of the strategic lines of action for the achievement of PEAASAR main objectives (MAOTDR, 2007).

In terms of availability of equipment for the capture and storage of rainwater, there are already some products in the Portuguese market. These include both complete rainwater harvesting systems (RWHS) (for example, in high-density polyethylene- HDPE) and individual components for non standard systems. Alternatively, there are companies that buy the individual components to the manufacturers and provide the service of installing the systems. There is always the option of concrete tanks; these can be built by any civil construction company.

In a general, rainwater harvesting systems are constituted by components for the following basic functions: capture, transport, filtration, storage, distribution and treatment. The capture includes a surface on which the rain falls called catchment surface. The transport is composed of components that allow water to travel from the roof to the tank, including gutters and downspouts. The filtration covers devices that remove debris and dust from rainwater captured before reaching the tank, such as the leaf screens, the first flush diverters and the roof washers. The storage can be done in one or more tanks, often also called cisterns. The distribution is the transport system of rainwater to its end use point, and can be by pumping or gravity. The treatment is applied only to potable systems, where filters and other methods are used in order to have the suitable water for human consumption; therefore not needed for the systems covered by the present study (TWDB, 2005).

The general objective of this work is the contribution for the evaluation of viability of rainwater harvesting in non-potable urban uses in Portugal, through the elaboration of a user friendly simulator which can be used to evaluate the local potential of harvesting for the specific circumstances in different applications.

The simulator was elaborated based on other existent applications such as the simulator RainCycle (2005) and the programme described in Manual of TWDB (2005). The software Raincycle is an easy to use simulator, in an Excel spreadsheet, which allows modelling and analysing the installation of rainwater harvesting systems in domestic, commercial, public or industrial buildings. This tool includes a detailed hydraulic model of a typical rainwater harvesting system and has also the ability to explicitly account all major costs associated with these systems (RainCycle Advanced, 2005; Roebuck *et al.*, 2006; SUD Solutions, 2005; SUD Solutions, 2006). The Manual of TWDB (2005) presents an Excel spreadsheet that allows users to carry out water balance calculations for the sizing of rainwater harvesting systems. These tools do not use comprehensive information on local rainfall patterns, thus being limited in characterising the source of water.

The specific objectives are: identify actual practices of rainwater harvesting for non-potable urban uses in Portugal and in foreign countries; identify the potential and the barriers of rainwater harvesting in non-potable uses based on divulged cases in bibliography; identify the strengths and weaknesses, opportunities and threats of rainwater harvesting systems through a SWOT analysis; elaborate a simulator for sizing and analysis of benefit in different applications in residential sector or in installations of larger dimension, in different regions of Portugal; apply and test the simulator in case studies; and identify the situations where RWHS has more potential.

The SWOT analysis was used to synthesize the main aspects relevant for the analysis of viability of rainwater harvesting systems. The results obtained in this analysis appear in Table 1.1.

Table 1.1- Results obtained in SWOT analysis

Strengths	Weaknesses
• Reduces the consumption of main water and the associated cost; • Reduces the exploitation costs of water supply systems; • Reduces the rainwater volume launched in wastewater and rainwater system, contributing to control the floods, the efficiency of WWTP and the discharge of water potentially polluted in receiving environment; • Decreases the groundwater reserves dependence which exhaust when super-exploited; • The technologies are simple to install and easy to handle what reduces the installation and maintenance costs; • The appropriate components and materials are available in the market; • The watering with water without chlorine is beneficial to the plants.	• Limitation of harvested rainwater quantity in the tank due to the temporal variability of the precipitation; • The system can implicate a significant initial investment; • Absence of national legislation that specifically regulates the rainwater harvesting.
Opportunities	**Threats**
• Technological innovations have been reducing the investment cost; • The market of rainwater harvesting has been increasing and a greater number of solutions are available; • In the context of climate change, the water availability decreasing reinforces the need of this type of system.	• Existence of national legislation that emerges as an obstacle to enable application of this technique (the DL 23/95 prohibits the use of non-potable water in building networks, especially, in flushing cisterns; some council regulations do not allow the connection of wells or other water sources to the pipe installation inside the buildings); • There are devices, systems and equipments that are not certified so if the solutions do not have a recognized quality, it can lead to loss of interest in the use of rainwater systems; • Lack of people information can lead to the no acceptance of this technique; • The concentration and the intensification of precipitation phenomena will require a greater transport capacity from catchment surface to the tank and a larger tank volume to face the dry periods which tend to be drier.

Observing Table 1.1, it is possible to note that rainwater harvesting is a technique with many strengths when compared with the weaknesses and, therefore, it can be assumed that its application could bring enormous advantages to the resolution of problems such as the scarcity of potable water, without serious consequences for the environment and for the people. The main threats to its application in Portugal are the absence of legislation that specifically regulates this technique; the existence of legislation that emerges as an obstacle to enable its application and the existence of devices, systems and equipments that are not certified what can lead to the loss of interest of people by the lack of solutions with quality (Almeida *et al.*, 2005).

2 Methodology

2.1 General structure

The general structure adopted for the simulator (programmed in Visual Basic for Applications – VBA in Excel environment) is divided in five big blocks: the data introduction module, the calculation cycle, the efficiencies calculation module, the economic analysis module and the results presentation module.

In addition two introductory spreadsheets, one that constitutes a face page and another where is available the user instructions, are included.

2.2 Data introduction module

In this stage, the user must proceed to the introduction of data in the simulator and to the selection of the nearest rain gauge to the local where installation of the RWHS is intended, following the instructions spreadsheet. The data introduced in the data spreadsheet include: tank dimensions (minimum and maximum dimensions); data about to the RWHS (rain gauge, catchment area, runoff coefficient and filter coefficient); data related to the consumption (consumption factor, frequency of toilet daily use per person, water volume in each toilet use, number of people using the facilities, number of floor cleanings per week, water volume per floor cleaning, number of car cleanings per week, water volume in each car cleaning, number of cars in the family, garden area, daily volume use per unit area and water volume in other uses) and data for the economic analysis (average tariff of main water consumption, discount rate and estimated cost of the tank for dimensions to be considered).

2.3 Calculation cycle

The simulation is made for each one of the ten established capacities for the tank, being the balance of volumes calculated, day by day, during a ten years period (1997-2006). The adoption of day interval in calculations is not applicable in events with a higher intensity of precipitation. In this cycle are determined the following volumes: the water volume precipitated in the catchment surface, the water volume captured by RWHS, the consumption, the rainwater volume stored, the rainwater volume in excess in the tank, the volume available in the tank, the water volume used from the WSS and the saving water volume.

2.4 Efficiencies calculation module

The comparison of results for the alternatives tank volumes is facilitated if criteria allowing the assessment of the efficiency, under different points of view, are used. In the present application, efficiency measures selected and calculated were: efficiency in the use of the available storage capacity; efficiency of the rainwater harvesting system and percentage of water volume associated to compatible uses with the use of non-potable water.

2.5 Economic analysis module

In this module the parcels of cost (cost of tank installation) and the benefits (cost of saving water), considered relevant to select the more favourable tank dimension for each case, are determined. The investment recovery period for each tank dimension is also calculated to help the user to analyse the viability of RWHS in his specific case.

2.6 Results presentation module

The final block of the simulator is related to the results presentation. In this block are included synthesis tables and graphics to illustrate the results for each considered tank dimension. The results contain: volumes (volume stored in the tank, volume discharged into the sewage, volume not used in the tank, potable water consumption and non-potable water consumption); efficiencies (efficiency in the tank use, percentage of water volume in compatible uses with the use of non-potable water and efficiency of RWHS) and the economic analysis results (cost of tank installation, total cost of saving water, difference between the benefit and the cost and investment recovery period).

3 Application to the case studies

3.1 Case studies selected

The simulator was applied to three case studies in different regions of Portugal. The cases selected were the following: detached house located in the village of Toito, district of Guarda; building of offices and laboratories located at LNEC campus, in Lisbon, and detached house, in the city Estômbar, district of Faro.

3.2 Detached house in Toito, Guarda

The installation considered in this case study is a detached house localized in the centre of a small village belonging to the district of Guarda (Beira Alta), known as Toito.

The uses considered are, among others, the toilet flushing, floors cleaning, car washing and the watering of gardens.

With the objective to compare the costs of tanks built with different materials, two alternative solutions of tanks for the rainwater harvesting system were considered: a buried tank in concrete and a buried tank in HDPE.

3.3 Building of offices and laboratories at LNEC, Lisbon

The installation considered in this case study is a building of offices and laboratories localized at LNEC campus, in Lisbon (Estremadura).

The uses included are: the watering of gardens, toilet flushing and floors cleaning. It is also assumed that the tank used is buried and built in concrete.

3.4 Detached house in Estômbar, Faro

The installation considered in this case study is a detached house localized in Alameda do Algarve, in Estômbar, city belonging to the municipality of Lagoa and the district of Faro (Algarve).

The rainwater is used in toilet flushing and car washing, among others uses. The tank used is buried and built in HDPE.

4 Discussion of results

The tests of the simulator showed that this tool is very useful for supporting in the selection of the RHWS, allowing the calculation of daily balance of volumes, the determination of several efficiencies and the economic analysis of RHWS so that the user could evaluate the viability of rainwater harvesting in his specific case. From Figure 4.1 to Figure 4.3 are presented the graphics obtained in the simulator for the case study LNEC-Lisbon that corresponds to the case study where the results are more favourable in economic terms.

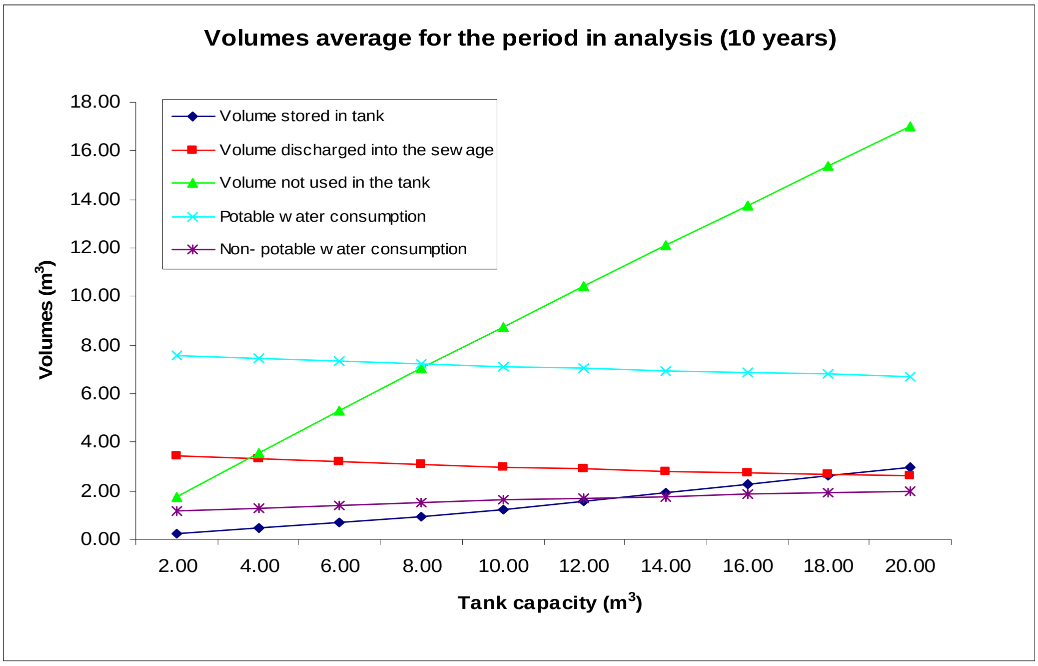
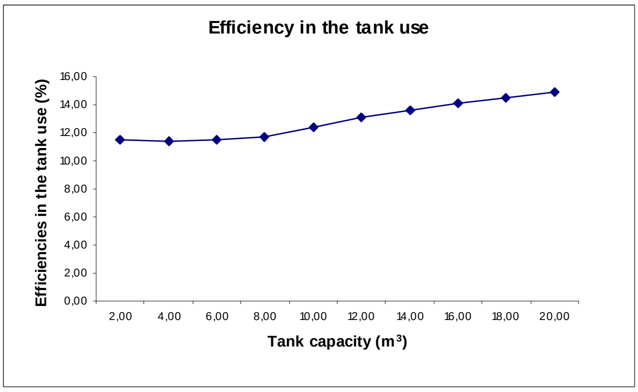
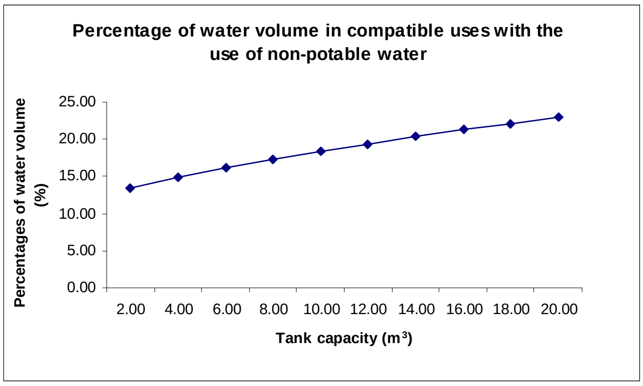


Figure 4.1- Graphic of the volumes average for the period in analysis (10 years) in case study LNEC-Lisbon





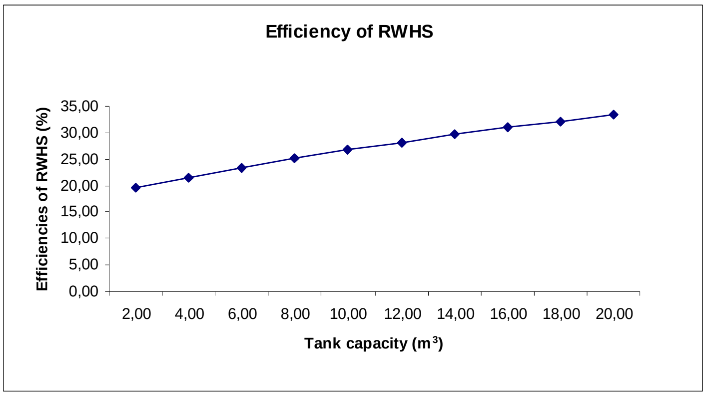


Figure 4.2- Graphics of efficiencies in case study LNEC-Lisbon

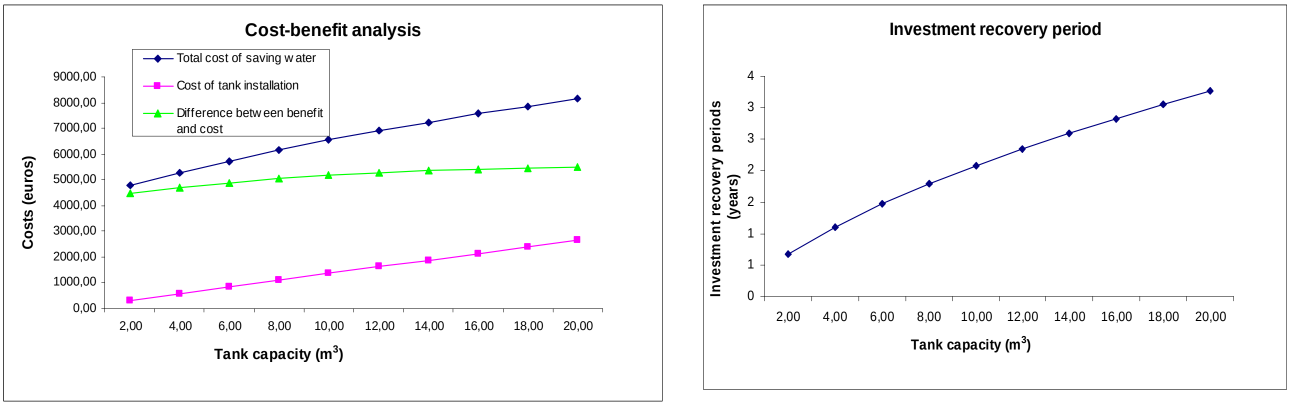


Figure 4.3- Graphics of economic analysis in case study LNEC-Lisbon

As expected, increasing tank capacity leads to increasing the volume stored in the tank, the available storage volume in the tank and the non-potable water consumption while leads to the decrease of the volume discharged into the sewage and the potable water consumption. In terms of the efficiencies, the percentage of water volume in compatible uses and the efficiency of RWHS increase as the tank capacity increase, however the efficiency in the tank use decreases until $V=4m^3$ and after that increases. Finally, for the economic analysis, balance of the costs as well as the investment recovery period increase with tank capacity. In this case study, independently of the tank capacity, the benefit is always higher than the cost. From the economic point of view, this is very advantageous. The tank capacity economically more favourable is the tank capacity 10 with the value of 20 m^3 to which corresponds an investment recovery period of 3 years. Base on the results, it can be concluded that the installation of a rainwater harvesting system in this specific case would be feasible and, eventually, larger storage volumes could be considered, if local conditions permitting.

In the remaining case studies, while the general trend is similar to the case study LNEC-Lisbon, benefits are lower but efficiencies more favourable.

In Table 4.1 a synthesis of the results obtained for the selected tank capacities, in each case study, are presented.

Table 4.1 - Main results obtained for the tank capacities with the more favourable benefit in each case study for the period in analysis of 10 years

Quantities	Case studies			
	Toito-Guarda		LNEC-Lisbon	Faro
	Concrete tank	HDPE tank	Concrete tank	HDPE tank
Tank capacities more favourable (m^3)	1,00	1,00	20,00	1,00
Daily volume stored in tank (m^3)	0,19	0,19	2,97	0,17
Daily volume discharged into the sewage (m^3)	0,09	0,09	2,59	0,13
Daily volume not used in the tank (m^3)	0,81	0,81	17,03	0,83
Potable water daily consumption (m^3)	0,17	0,17	6,73	0,22
Non-potable water daily consumption (m^3)	0,09	0,09	2,00	0,10
Efficiency in the tank use (%)	19,06	19,06	14,86	16,67
Percentage of water volume in compatible uses with the use of non-potable water (%)	34,62	34,62	22,92	30,83
Efficiency of RWHS (%)	39,57	39,57	33,32	33,43
Cost of tank installation (€)	189,60	263,30	2662,83	263,30
Total cost of saving water (€)	205,24	205,24	8149,82	129,17
Difference between the benefit and the cost (€)	15,63	-58,07	5486,98	-134,13
Investment recovery period (years)	9,24	12,83	3,27	20,38

Results in Table 4.1, emphasizes that water savings are highest in the LNEC-Lisbon case study while presenting the highest difference between benefit and cost and the more reasonable investment recovery period.

In relation to efficiencies, the case study Toito-Guarda is the one that presents the highest values, because the tank capacity selected is probably the capacity that better adapts to the volume of water that reaches the tank and to the volume of rainwater that is consumed.

Comparing the economic analysis of the two types of tanks considered in case study Toito-Guarda, the better choice would be the concrete tank since HDPE tanks leads to higher costs installation tank.

Through the exposed previously, it is possible to say that, from the economic point of view, the installation of a rainwater harvesting system is more favourable in situations with higher non-potable water consumptions and larger catchment areas (for example, hotels, shopping centres).

5 Conclusions

Based on the SWOT analysis and on the results of the simulator, it can be concluded that the rainwater harvesting in urban uses in Portugal is an important technique which contributes to attenuate problems such as the lack of potable water. This can especially be relevant in the regions facing period of water scarcity during the summer months. However, since the main water price is still relatively low in Portugal, the installation of a rainwater harvesting system is not always the more favourable solution in economic terms. In cases where installations have high non-potable water consumptions and larger catchment areas (for example, hotels, shopping centres) the economic benefit is higher.

Today, in Portugal, this technique is still incipient and, therefore, it would be relevant the adoption of measures to increase awareness of the people to the problems such as the scarcity of potable water and, in this sequence, present the rainwater harvesting as a way to attenuate these problems. Possible actions are included in the National Plan for the Efficient Use of Water (Baptista *et al.*, 2001).

Especially relevant are the regulations and standards, in order to safeguard public health and assure the use of efficient systems.

The simulator allows users to explore the possibilities and estimate the benefits of a RWHS and utilises local data on rainfall, thus permitting a better estimation of the benefits of the rainwater harvesting system.

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