

Assessment of Urban Rainwater Harvesting Potential in Portugal: A Spatial Approach Using the C Index

Évaluation du Potentiel de Récupération des Eaux Pluviales Urbaines au Portugal : Une Approche Spatiale Utilisant l'Indice C

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RÉSUMÉ

Les changements climatiques exigent de plus en plus des stratégies solides capables d'orienter la société vers des trajectoires plus durables. Les systèmes de récupération des eaux pluviales (RWHS) constituent un outil éprouvé et efficace dans cette transition, contribuant non seulement à la préservation des ressources hydriques, mais également à l'atténuation des inondations urbaines et à la réduction de la demande sur les réseaux publics d'approvisionnement en eau. La présente étude a appliqué une méthodologie visant à évaluer le potentiel de chaque municipalité portugaise pour l'implantation de RWHS, en calculant l'Indice C et en intégrant la typologie des zones bâties (Classe 1, Classe 2 et Classe 3), la précipitation et la consommation d'eau. L'ensemble des analyses spatiales a été réalisé dans QGIS. Les résultats ont démontré la faisabilité de l'implantation des RWHS, en particulier dans les municipalités situées dans le nord et le centre du Portugal. Au total, 22 municipalités de Classe 1 et 2 municipalités de Classe 2 ont été identifiées comme ayant la capacité de satisfaire entièrement la demande en eau de leur population grâce à l'eau de pluie récoltée.

ABSTRACT

Climate change increasingly demands robust strategies that can guide society toward more sustainable pathways. Rainwater Harvesting Systems (RWHS) constitute a proven and effective tool in this transition, contributing not only to the preservation of water resources but also to the mitigation of urban flooding and the reduction of demand on public water-supply networks. The present study applied a methodology to assess the potential of each Portuguese municipality for RWHS implementation by calculating the C Index, incorporating built-area typology (Class 1, Class 2, and Class 3), precipitation, and water consumption. All spatial analyses were carried out in QGIS. The results demonstrated the feasibility of RWHS deployment, particularly in municipalities located in northern and central Portugal. A total of 22 Class 1 municipalities and 2 Class 2 municipalities were identified as having the capacity to meet their population's water demand exclusively through harvested rainwater.

KEYWORDS

C Index Method, Location Optimization, Portuguese Municipalities, Rainwater Harvesting Systems, Sustainable Water Management.

1 INTRODUCTION

Rainwater Harvesting Systems (RWHS) have emerged as a viable alternative in scenarios of water insecurity (Amos et al., 2016). RWHS have been shown to positively contribute to several additional aspects, including the attenuation of flood risks in urban centres, support for the hydrological cycle, and reduction of demand on public water supply systems (Raimondi et al., 2023). Previous studies highlight the importance of RWHS in regions affected by water scarcity and in sustaining long-term environmental resilience (Lepcha, 2024; Feloni & Nastos, 2024; Rahman et al., 2014). The collection and utilisation of rainwater is therefore consistent with the principles of efficient water-resources management.

Despite their benefits, several barriers still hinder the widespread adoption of RWHS. The most significant challenges include installation and maintenance costs, limited public awareness (Medeiros, 2014; Szoldrowska et al., 2025), and the technical difficulty of designing systems that appropriately account for local rainfall variability (Szoldrowska et al., 2025) and territorial configuration (Raimondi et al., 2023). The absence of specific legislation and the limited availability of studies at the municipal level further constrain the advancement of these systems (Medeiros, 2014). Empirical evidence from Brazil, Poland, and Germany demonstrates the efficiency of RWHS in reducing demand on public water networks (Burszta-Adamiak, 2025; Tasiwuka, 2025; Fewkes, 1999).

Consequently, optimising RWHS requires the identification of suitable locations for system implementation, as well as the selection of storage structures aligned with local environmental and socio-economic conditions. This necessitates an assessment of regional realities and the use of comparative metrics to determine optimal zones for RWHS installation (Li et al., 2016). Among the existing metrics, the C Index incorporates average precipitation, water demand, and catchment area. A C value of 1 indicates that the locality can fully meet its water demand using only rainwater harvesting. For $C < 1$, rainwater alone is insufficient, requiring supplementary public supply. Conversely, $C > 1$ indicates that harvested rainwater exceeds local water demand.

The present study adopts the built-area classification defined by the Directorate-General for Territory (DGT), comprising: Class 1 (areas with 10 or more residential buildings); Class 2 (isolated or dispersed areas containing 1 to 9 residential buildings); and Class 3 (non-residential areas).

Considering the elements outlined above, this study applies the C Index to evaluate the potential for rainwater harvesting across the 278 Portuguese municipalities, taking into account their built-environment typology, thereby determining the spatial distribution of rainwater-harvesting potential.

2 MATERIALS AND METHODS

The study area corresponds to mainland Portugal, a territory encompassing approximately 92,000 km² and administratively divided into 278 municipalities. All geospatial analyses were conducted using QGIS 3.22.3. Precipitation data were obtained from raster files containing historical rainfall values. Per-capita water consumption was extracted from the Portuguese National Institute of Statistics (INE) for the period 2011–2019, along with population data from the INE Census (resident population by municipality). Average municipal consumption (Q) was calculated by multiplying the municipal population (inhabitants) by the corresponding municipal per-capita water consumption (m³ per inhabitant).

Data on built-area typology (A), defined by Class 1, Class 2, and Class 3, were obtained from the Directorate-General for Territory (DGT) through the Shapefile Carta de Áreas Edificadas 2018. This enabled the determination, for each municipality, of the built-up area (A, m²), average precipitation (P, m), and average water consumption (Q, m³).

Thus, by multiplying P by A and dividing by Q, the dimensionless C Index is obtained. Three C-Index categories were established to support the analysis: $C < 0.95$; $0.95 \leq C \leq 1$; $C > 1$. Municipalities were subsequently classified according to their respective category.

3 RESULTS

The C Index was calculated for all 278 Portuguese municipalities.

For Class 1, the number of municipalities within each category was determined as follows: 251 municipalities - $C < 0,95$; 5 municipalities - $0,95 \leq C \leq 1$; 22 municipalities - $C > 1$. The 22 municipalities with $C > 1$ are listed below together with their corresponding C values: Sever do Vouga (5.276); Mondim de Basto (2.406); Oliveira de Frades (2.116); Monção (2.020); Gouveia (1.699); Paredes (1.697); Montalegre (1.603); Vale de Cambra (1.588); Celorico de Basto (1.572); Vieira do Minho (1.481); Santa Maria da Feira (1.374); Ovar (1.354); Santo Tirso (1.320); Oliveira de Azeméis (1.294); Vila Nova de Cerveira (1.244); Avis (1.154); Figueira de Castelo Rodrigo (1.138); Carregal do Sal (1.111); Nisa (1.048); Arcos de Valdevez (1.039); Rio Maior (1.038); and Vila Nova de Famalicão (1.033).

For Class 2 the distribution of municipalities was as follows: 276 municipalities - $C < 0,95$; 0 municipalities - $0,95 \leq C \leq 1$; 2 municipalities - $C > 2$. The municipalities with $C > 1$, along with their respective values, are: Sever do Vouga (1.329) and Albergaria-a-Velha (1.056).

For Class 3, the results indicate that all 278 municipalities fall within the category $C < 0,95$; 0 municipalities - $0,95 \leq C \leq 1$; 0 municipalities - $C > 0$.

4 DISCUSSION

The results indicate that the C Index is effective in identifying suitable zones for the implementation of RWHS. Areas with high precipitation but limited built-up area tend to exhibit low C values; similarly, locations with high water consumption but low precipitation also yield low C values. This assessment enables the identification of regions with the highest potential for hosting rainwater-harvesting structures (Vilar-Navascués et al., 2020).

It is evident that Class 1 contains the largest number of municipalities within the $C > 1$ category. This is attributable to the pluviometric and urban characteristics of Portugal. These areas are predominantly located in the northern and central regions of the country. The results were expected, as the North exhibits the highest rainfall indices, while the coastal regions contain the highest population density. Notably, the municipality of Sever do Vouga presents $C > 1$ for both Class 1 e Class 2.

Almeida et al. (2021) report that most studies employing the C Index focus on isolated buildings and often rely on daily precipitation data, which can influence the results. In a study conducted for a building in Lisbon, Lúcio et al. (2020) observed water savings ranging from 16% to 86%. In contrast, for Lisbon, the present study identified a maximum C value of 0.111 (11%). The literature also supports the economic feasibility of implementing RWHS in humid and semi-humid regions (Jing et al., 2017).

A comparison with the study by Silva (2015), conducted for residences in the municipalities of Porto and Almada, reveals that similar C Index values can be obtained despite differences in average precipitation. The values reported by Silva (2015) and those obtained in the present study were, respectively: $P = 1.44$ m, $C_1 = 0.513$, $C_2 = 0.0010$, $C_3 = 0.001$; $P = 0.73$ m, $C_1 = 0.18$, $C_2 = 0.005$, $C_3 = 0.004$.

5 STUDY LIMITATIONS

As limitations, it is noted that by considering an average precipitation value, seasonal variations are excluded, which may lead to inaccuracies in the sizing of RWHS. Since the present analysis was conducted at the national scale, a municipality-focused study could yield more precise results. The municipality of Sever do Vouga, for instance, should be examined in greater detail.

Moreover, the C Index does not account for the storage capacity of rainwater reservoirs, a factor that must be considered in accordance with local conditions.

6 CONCLUSION

It is evident that RWHS constitute a system with significant potential to contribute to the conservation of water resources. In the context of global population growth, intensifying drought periods, and decreasing predictability of precipitation patterns, RWHS have been consistently shown to be an important tool for environmental conservation.

This study conducted an analysis based on built-area classes, which enables the distinction between more densely and less densely developed areas, thereby supporting the development of solutions tailored to local conditions. With regard to the spatial assessment of suitable zones for RWHS implementation, the existing literature provides limited research at national or municipal scales; most studies focus on individual buildings, adopting a site-specific approach.

Thus, the present study made it possible to determine the potential for RWHS implementation in each municipality of mainland Portugal and to identify those with the capacity to meet their population's water demand through the storage of rainwater.

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