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Assessment of Rainwater Harvesting Potential from Roof Catchments through Clustering Analysis

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Abstract: Rainwater harvesting from rooftop catchments represents a climate change adaptation measure that is especially significant in areas affected by water scarcity. This article develops a Geographic Information Systems-based methodology to evaluate the spatial distribution of rainwater catchment potential to identify the most favorable urban areas for the installation of these infrastructures. Since performance and water saving potential of rainwater harvesting systems greatly depends on population density and roof size, this assessment was performed for each residential plot on a per capita basis, based on cadastral data and a method of demographic disaggregation. Furthermore, to evaluate spatial variation of runoff coefficient per building, a supervised classification was carried out to consider the influence of roof types on the rainwater catchment potential. After calculating rainwater catchment potential per capita for each residential plot, the spatial clustering of high (hot spots) and low values (cold spots) was assessed through the Getis-Ord General G statistic. Results indicate a spatial pattern of high rainwater catchment potential values in low-density urban areas, where rainwater catchment systems are expected to offer a better performance and a shorter amortization period. These results may be useful for the enactment of local legislation that regulates the obligation to install these infrastructures or offers subsidies for their implementation.

Keywords: rainwater harvesting; GIS; spatial analysis; water consumption; Spain

1. Introduction

Growing water demand in urban areas has led to the development of non-conventional supply sources worldwide, especially in regions with a Mediterranean or semi-arid climate affected by water scarcity [1]. In these regions, the use of rainwater tanks or 'aljibes' was widespread for domestic water storage, but they have gradually fallen into abeyance following the development of regional water supply systems [2]. An effort is being currently made to recover this customary practice to satisfy water demand in accordance with the principles of sustainability and water efficiency [3,4]. The promotion and development of rainwater harvesting systems (RWHS) also represent an adaptation measure to the reduction of the availability of water resources forecast by climate projections [5]. Over the past few decades, RWHS development has taken place around the world to cope with water scarcity [6], since most domestic demand can be satisfied with low quality water [7]. This means that rainwater can substitute higher-quality potable water in outdoor uses (watering the garden and washing the car) and indoor uses (cleaning, washing machine, and toilet flushing). The use of different water supply sources depending on the quality required by domestic uses involves the introduction of the fit for purpose principle in the domestic water supply, normally used in the scope of reclaimed water [8]. Hence, the implementation of this infrastructure in building design enables reducing water demand from conventional sources. Likewise, the spread of RWHS would also reduce urban runoff during intense storms, reduce water treatment and distribution costs [9], and decentralize water supply management [10].

However, the spreading of RWHS is primarily hindered by the economic costs of installation [11]. Therefore, some countries have taken legislative action aimed at promoting installation and facilitating return on investment [12]. In recent decades, the governments of Germany, Australia, Japan, France, Italy, Portugal, the United Kingdom, and the State of Texas (USA), among others, have established a regulatory framework and specific design protocols for installing RWHS [12,13]. The case of Australia is paradigmatic, since around 1.7 million households have rainwater tanks that provide between 8% and 14% of the water used for domestic purposes [12,14]. Beyond this case, the promotion of these infrastructures is growing around the world. The installation of RWHS has been required in newly constructed buildings with an area of more than 10,000 m^2 in Taiwan since 2003 [15]. In India, demographic growth has led to the mandatory installation of RWHS in many cities, such as Delhi and Chennai [16]. Likewise, its implementation has also been successful in France, where 15% of the population deploys rainwater for non-potable uses [7]. In Spain, the installation of RWHS is referred to in the Spanish Urban and Local Sustainability Strategy approved in 2011 and the Guide for the Development of Local Regulations in the Fight against Climate Change [17]. However, in Spain, operational and maintenance recommendations for these infrastructures and their water quality standards have not yet been developed [18]. Despite this situation, some municipalities in Catalonia, a region in north-east Spain, have already approved regulations aimed at saving water resources and promoting the installation of RWHS in residential buildings [18,19]. The success of these measures is explained by the wide acceptance of the use of rainwater owing to its simplicity, its limited environmental impact, and the promotion of water self-sufficiency [18]. In fact, among the non-conventional resources, the use of rainwater for domestic non-potable uses is the most popular option among the local population [20].

The Rainwater Catchment Potential Estimation

A great deal of literature has been produced to study how to improve the efficiency of these infrastructures and facilitating their proliferation, mainly in the field of civil engineering [21]. Through simulation models and water balance equations, these studies have focused on establishing the optimum storage tank size and assessing the water-saving potential at building level [22]. These models are determined by certain parameters, such as roof size, water demand, or rainwater tank size; consequently, these investigations focus on a technical perspective applied at the building scale [23]. From a theoretical perspective, another type of studies focuses on the assessment of the potable water saving potential resulting from a mass implementation of RWHS at different scales: national [15], regional [24], or urban [13]. Research has been carried out for case studies with very different rainfall patterns, such as Jordan [25], France [13], Brazil [24,26], Colombia [27], and China [6]. As a preliminary step to evaluating the potential water savings, rainwater capture and harvesting potential (RCHP) must be calculated. To calculate this, the Formula (1) is applied [28,29].

$$\mathrm{RCHP} = (\mathrm{TRA} \times \mathrm{P} \times \mathrm{RC})/1000 \tag{1}$$

where TRA is the total roof area expressed in square meters, P is the precipitation in liters per square meter or millimeters (mm) for a specific period (monthly or annual), and RC is the runoff coefficient, a dimensionless value that estimates the proportion of precipitation that reaches the rainwater tank discounting the losses caused by spillage, wetting of the catchment surface, and evaporation [30]. For the calculation of TRA, land registry information is typically used, since this information enables a spatial differentiation of the catchment area and the type of building [31]. Secondly, the average precipitation values are commonly used for a 30-year series [24]. Likewise, in areas with considerable inter-annual variation, the RCHP is estimated for different rainfall scenarios [27]. Other studies give greater importance to seasonal rainfall variability for analyzing its impact on water-saving potential since seasonality affects the performance of RWHS [28,29]. Thirdly, to assess the runoff coefficient (RC) most research uses a fixed value without considering the influence of the rooftop slope and material. This may lead to an incorrect estimation of the catchment potential of a building, especially in municipalities with a great variety of building types, as occurs on the Spanish Mediterranean coast [30].

Once the RCHP has been obtained for a spatial area, the theoretical water saving potential is then calculated using monthly or annual water consumption data [24–27]. This calculation implies an overestimation of the water-saving potential, since it disregards key aspects that limit the use of rainwater such as storage capacity or rainwater consumption in each building [15]. Some studies have determined that theoretical water-saving potential overestimates the actual rainwater availability by 30% [7]. For these reasons, the study of potential theoretical water savings derived from a massive RWHS installation at the city scale presents numerous biases. Instead of calculating the water-saving potential resulting from the massive installation of RWHS across the city, the spatial analysis of the catchment potential of rainwater harvesting may be more useful for both city planners and utility managers [32–35]. Some studies have evaluated that under similar climatic conditions the most relevant factors influencing RWHS performance are population density and roof size [32–36]. Therefore, the RCHP per capita may be a useful indicator of the areas with greater water-saving potential, since it is possible to calculate it on a city scale without having to consider rainwater demand or the size of the tank. In this way, it is possible to spatially identify the suitability of installing this infrastructure. Hence, a spatial focus on RCHP per capita at an urban scale may be most relevant for local-decision makers when applying rainwater harvesting pilot programs [35].

This paper develops and applies a methodology to assess RCHP per capita at the urban level to identify the most favorable residential areas for RWHS installation. This research is developed in the city of Alicante, located in southeast Spain on the Mediterranean coast (Figure 1). The article is structured in three sections. In the first part, materials and methods are described. After that, the results are presented and, finally, in the conclusions and discussion section, the limitations and benefits of the method used are identified, and we propose future lines of work.

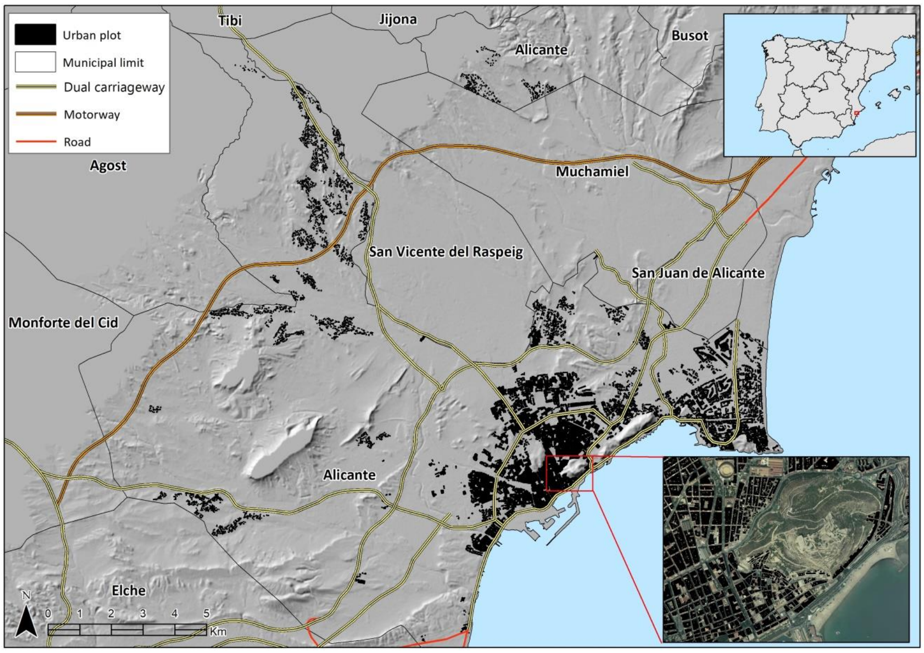

Figure 1. Location of the study area and distribution of residential plots.

2. Materials and Methods

The methodology used was divided into two sequential stages. Firstly, the procedure to estimate the rainwater capture and harvesting potential (RCHP) per capita in residential buildings was undertaken, considering the spatial variability of the runoff coefficient. Data sources and methods used to calculate each of the parameters involved in the calculation of the RCHP equation are described below. Secondly, the spatial distribution of RCHP per capita was analyzed based on the calculation of the Getis-Ord General G statistic, which measures the clustering of high and low values in the study area. The working method is summarized in Figure 2.

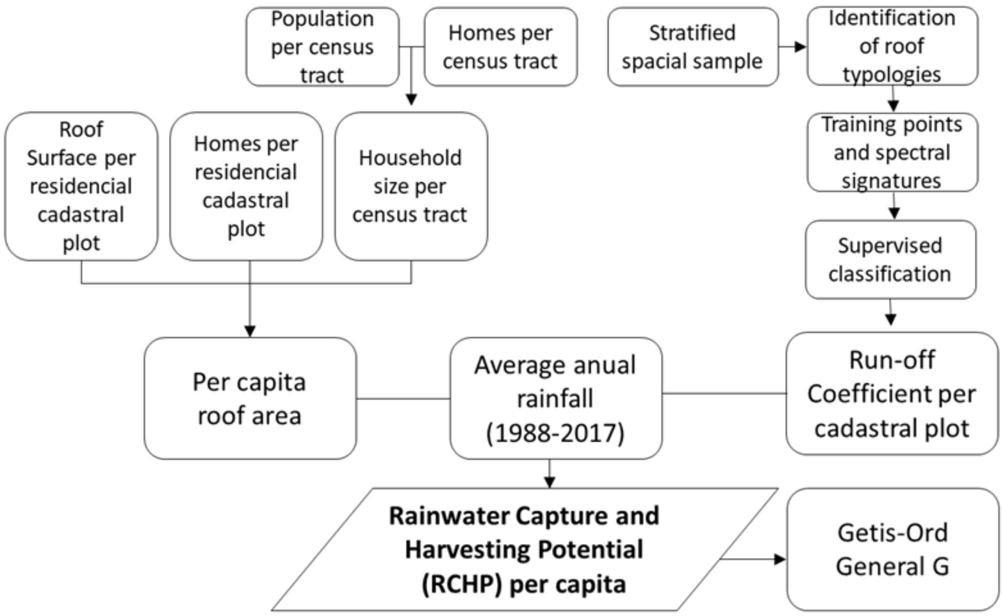

Figure 2. Summary of the working method.

2.1. Roof Area per Capita

The information on urban building roof areas was obtained from the Directorate-General for the Cadaster's electronic office [37]. With this information, a spatial database was created using geographic information systems (GIS). The land registry cartography was filtered, and only residential urban plots were selected. These represent 87% of all urban plots and 63% of the total built area. To overcome the lack of demographic information at a lower level than that of the census tract, the population for each residential plot was disaggregated according to the method proposed by Maantay and Maroko [38]. Subsequently, roof area per capita (m^2/inhabitant) was calculated for use, assessing RCHP per capita for each residential building. This method is summarized in the following Formula (2):

$$\text{Roof area per capita} = \frac{\text{Total roof area}}{(\text{Household size per census tract} \times \text{Homes per residential plot})}. \quad (2)$$

2.2. Precipitation

Monthly precipitation data for a 30-year series (1988–2017) was used from the meteorological observatory in Ciudad Jardín (Alicante), which belongs to the main network of the Spanish State Meteorological Agency (AEMET). To show the influence of the inter-annual and seasonal rainfall variability over the RCHP, its monthly fluctuation is represented in boxplots. However, the spatial analysis of the RCHP per capita was made for average annual precipitation of 293.3 mm.

2.3. Runoff Coefficient

To mitigate the methodological limitations identified in the previous studies, a method has been designed for the calculation of the roof runoff coefficient (RC) at the residential plot level. This methodology comprises three stages. Firstly, a simple random sampling at a 90% confidence level and 10% maximum error was performed to identify visually through photointerpretation the roof types including both slope and roofing materials used. The total sample consisted of 1196 residential plots with a built area of 679,207 m^2, which represents 6.97% and 7.65% of the total for the city, respectively. To identify visually roof types the orthophotography of the Spanish National Aerial Orthophotography Plan (PNOA) was used for the year 2017 at 25 cm resolution and Google Maps (https://maps.google.es/) to check the previous diagnosis through the three dimensions viewer. Up to three types of roofs have been registered: sloping tiled roofs, flat roofs with asphalt sheets, and flat roofs with gravel. For each roof type, a runoff coefficient has been assigned extracted from the values used in other studies. For sloping tiled roofs, and flat roofs with gravel, an RC of 0.84 and 0.62 was used, respectively [30]. For flat roofs with asphalt sheets, an RC of 0.7 was applied [39]. Secondly, a supervised classification of the roof typologies described was carried out from the PNOA orthophotography. To do so, different training sites were selected for each roof type identified to create a file with their spectral signatures. In total, up to twelve spectral signatures were identified for the three roof types: five signatures for sloping tiled roofs, one signature for flat roofs with gravel, and six signatures for flat roofs with asphalt sheets. The supervised classification was carried out using the maximum likelihood classification method [40]. Thirdly, and lastly, the predominant roof type resulting from this classification has been calculated and its corresponding RC value assigned for each residential plot. To check the accuracy of the classifications, the kappa index was calculated based on the RC results in the sampled residential plots [41]. This index relates the observed matches with those attributable to chance and total observations.

2.4. Spatial Clustering

After calculating all the parameters that are part of the RCHP per capita equation, its spatial clustering was analyzed through the Getis-Ord General G spatial association statistic, using ArcGis software version 10.4 [42]. The method of Euclidean distance, with a neighborhood threshold of 1235.9 m and a fixed distance band, was used. This analysis, also known as hot spot analysis, is especially useful in cases where other spatial statistics, such as kernel estimation, K function analysis, Moran's I index, and semivariograms, do not show defined global spatial patterns [43]. Hot spot analysis enables the identification of localization patterns related to some attributes of spatial information for a study area as a whole [44]. The G statistic (3) is calculated with the following formula [45]:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(d) x_i x_j}{\sum_{i=1}^{n}\sum_{j=1}^{n} x_i x_j}, \ \forall j \neq i \tag{3}$$

where n is the number of units observed in the data set; x_i and x_j are the values of the roof area per capita measured for urban plots i and j, respectively; $w_{ij}(d)$ is the spatial weight between urban plots i and j; and $\forall j \neq i$ indicates that plots i and j cannot be the same. The statistic is general in the sense that it is based on all pairs of values, such that i and j are within distance d of each other [42]. Subsequently, the Z value is calculated, which indicates whether the observed value of the G statistic is significantly different from the expected value [G]. Therefore, if the local sum of the RCHP per capita in an area differs greatly from the sum of this potential in all the plots and the difference is too large to be attributed to spatial randomness, the result will be a statistically significant Z value (4), which will indicate the positive or negative sign of the spatial clustering. The formula used is the following [45]:

$$Z = \frac{G - E[G]}{\sqrt{V[G]}} \tag{4}$$

where $E[G]$ is the expected value of the G statistic (5) and $V[G]$ the variance of G (6) [42].

$$E[G] = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij\ (d)}}{n(n-1)}, \forall j \neq i \tag{5}$$

$$V[G] = E\left[G^2\right] - E[G]^2 \tag{6}$$

3. Results

Firstly, in this section the results of the supervised roof classification are analyzed. Secondly, the seasonal variation of the potential for stormwater harvesting at the city scale and the theoretical maximum water savings are evaluated. Finally, we analyze the spatial distribution and the clustering of potential rainwater catchment values.

3.1. Runoff Coefficient Assessment

The results of the supervised classification indicate that 78.1% of the sampled residential plots are correctly identified (Table 1). Likewise, these outcomes show a kappa index of 0.61, which represents a substantial strength of agreement [41]. The supervised classification is especially accurate for the sloping tiled roofs, since 84.6% of these roof types are classified successfully in the sample. Likewise, 75.8% of flat roofs with gravel and 71.4% of flat roofs with asphalt sheets are accurately classified.

Table 1. Results of the supervised classification on the sample of urban plots.

Roof Types	Visual Check (Residential Plots Sample)	Supervised Classification (Residential Plots)			Accuracy Rate
		Asphalt Sheets	Gravel	Tiles	
Flats roofs with asphalt sheets	528	377	15	136	71.4%
Flat roofs with gravel	95	17	72	6	75.8%
Sloping tiled roofs	573	77	11	485	84.6%
Total	1196	471	98	627	78.1%

The results of the supervised classification reveal that buildings with sloping tiled roofs are the most numerous and occupy the largest surface in Alicante (Table 2). However, four out of ten buildings have flat roofs with asphalt sheets, occupying a similar surface than buildings with sloping tiled roofs. The least numerous roof types are flat roofs with gravel, although they have a larger average area than the other types since they are usually located on apartment buildings. According to these results, the rainwater catchment potential for the whole city is 1,153,380 m^3 per year for an average rainfall scenario of 293.3 mm. If a fixed runoff coefficient of 0.8 had been used [24], instead of considering its spatial variability, the resulting rainwater catchment potential would have been oversized by 5.7%. Although this is a modest figure in overall terms, in flat roofs with asphalt sheets, the rainwater catchment potential oversizing would increase to 11.9%, and in flat roofs with gravel to 29%.

Table 2. Characteristics of the roof types in Alicante.

Roof Types	Residential Plots		Dwellings		Roof Surface		RCHP [1]	
	n	%	n	%	Total (m^2)	%	Volume (m^3)	%
Flats roofs with asphalt sheets	6815	39.7	94,281	48.6	2,197,165	42.2	451,100	39.1
Flat roofs with gravel	1064	6.2	21,037	10.8	580,221	11.1	105,511	9.1
Sloping tiled roofs	9280	54	78,715	40.5	2,422,227	46.6	596,769	51.7
Total	17,159	100	194,033	100	5,199,613	100	1,153,380	100

[1] Rainwater capture and harvesting potential.

3.2. Seasonal Variation of Rainwater Catchment Potential

For the whole city, there is a theoretical water-saving potential of 7.42%, considering a domestic water consumption of 14,435,505 m^3 according to the data provided for 2014 by the local water company. These results match with those of other studies in similar climatic areas [25]. However, the high inter-annual and seasonal rainfall variability produces large monthly variations in the RCHP and the theoretical water savings for an average rainfall scenario (Figure 3).

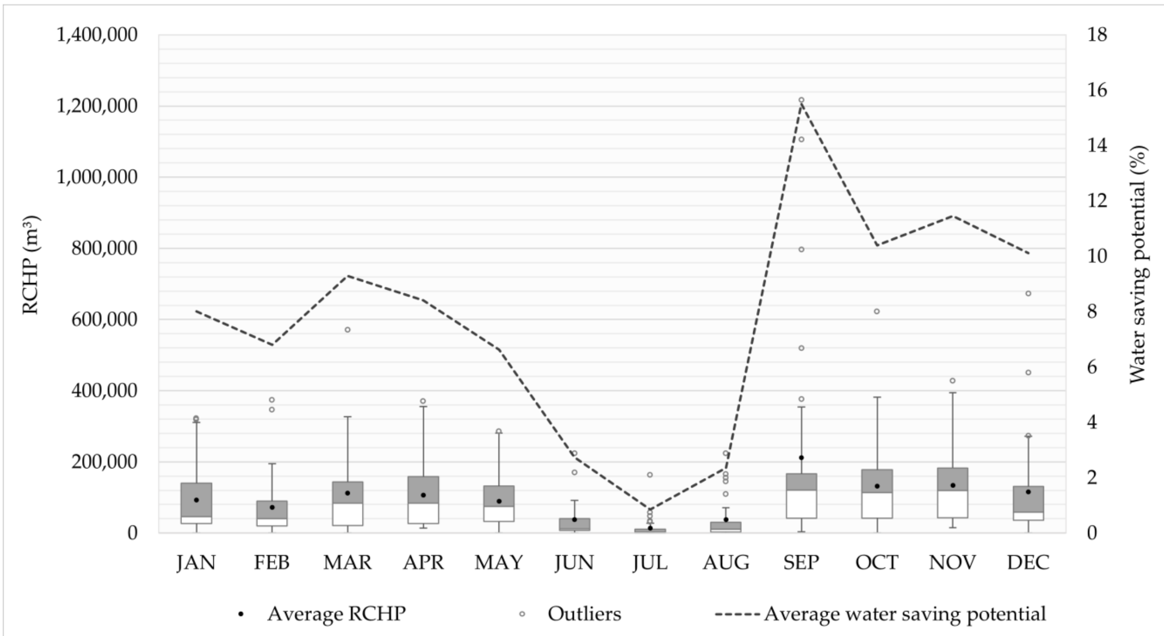

Figure 3. Rainwater Capture and Harvesting Potential (RCHP) monthly variability and theoretical water saving potential.

The recurring torrential rainfalls explain the abundance of outliers, the intensity of which is particularly high in September. Additionally, the monthly precipitation patterns over the last 30 years evidence the possibility of lack of rainfall all over the year. These conditions determine that RWHS in arid environments should be designed as an alternative water supply for non-essential uses, since the variability of precipitation reduces reliability. It should be also borne in mind that the irregularity and scarcity of precipitation are two factors habitually related to a lower RWHS performance [28,29]. For these reasons, in semiarid environments, it is crucial to consider the main parameters that affect the performance of the RWHS, which are population density and roof area [32,36]. Consequently, the RCHP per capita has been calculated after carrying out a population disaggregation method that has enabled calculating the roof area per capita for each residential plot. Accordingly, differences in roof area per capita between housing types should be emphasized (Table 3). While single-dwelling residential plots have an average per capita roof area of 54.8 m^2, this value is only 15 m^2 in multi-dwelling residential plots. Likewise, on average, single-family homes are able to capture 34.4 L of rainwater per capita and day, while multi-dwelling residential plots only 9.2. These differences help explain that even though single-dwelling residential plots only account for 3% of dwellings, they contribute 17.6% of the Alicante's rainwater capture and harvesting potential. Likewise, the average RCHP is only higher than 50 liters per person and day (18 m^3 per year) in urban plots with a roof area larger than 50 m^2 per capita. This issue implies that in the majority of cases RWHS should be installed in single-dwelling urban plots, since this buildings represent 13.86% out of 15.32% of the residential plots that have a roof area greater than 50 m^2. To spatially identify the residential plots with higher RCHP per capita, where greater rainwater harvesting yield is expected [35,36], it has been analyzed the clustering of high and low values.

Table 3. Residential plots, dwellings and RCHP according to type of building and roof area per capita.

Roof Area per Capita (m^2)	Single-Dwelling Residential Plots				Multi-Dwelling Residential Plots			
	Plots (%)	Dwellings (%)	RCHP [1] (%)	Average RCHP [1] per Capita (m^3)	Plots (%)	Dwellings (%)	RCHP [1] (%)	Average RCHP [1] per Capita (m^3)
0–5	0.04	0.00	0.00	0.81	4.24	15.55	5.7	0.88
5–10	0.17	0.01	0.01	1.79	22.75	48.07	34.6	1.70
10–15	0.63	0.05	0.07	2.96	15.48	22.37	25	2.68
15–25	3.25	0.27	0.61	5.03	11.42	8.27	7	4.43
25–50	18.85	1.57	6.28	8.61	7.04	2.34	7.5	7.65
>50	13.86	1.15	10.62	20.62	1.46	0.3	2.6	20.39
Total	36.81	3.08	17.6		62.41	96.93	82.4	

[1] Rainwater capture and harvesting potential.

3.3. Spatial Distribution of Rainwater Catchment Potential

To identify spatial patterns of RCHP per capita in the municipality of Alicante, the Getis-Ord general *G* spatial association statistic was calculated (Figure 4). This method enables t the per capita RCHP spatial clusters of high (hot spots) and low RCHP values (cold spots) [46].

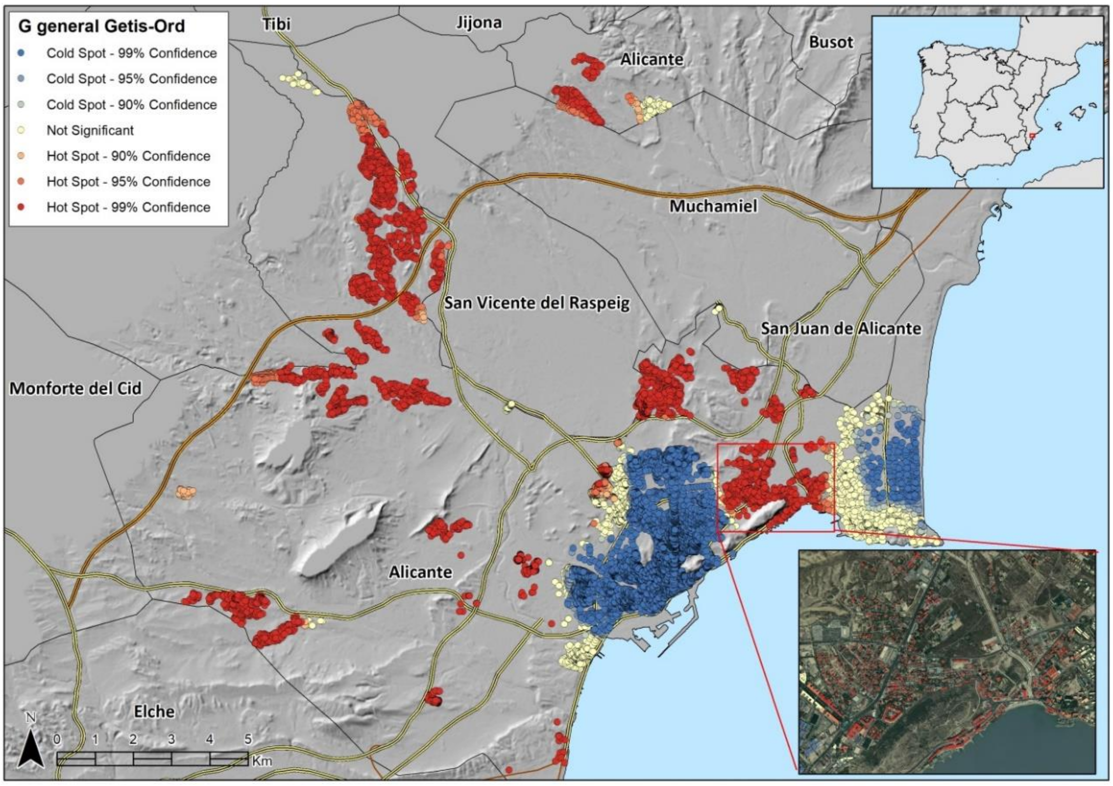

Figure 4. Spatial distribution of the Getis-Ord general *G* statistic.

Global statistics, such as the Getis-Ord General *G* statistic, assess the pattern and the general trend of the data [45]. This means that its effectiveness is greater when the spatial pattern is consistent throughout the study area. Therefore, in the areas of transition between hot and cold spots, where there is a greater diversity of housing types and RCHP per capita values, there is no statistically significant spatial clustering pattern (Figure 5).

In Alicante, 78.1% of residential plots belong to spatial clusters with a high statistical significance (p-value < 0.01), and 14.5% are not included in any cluster. The remaining 4.95% and 2.4% of the residential plots belong to spatial clusters with a confidence level of 95% and 90%, respectively. The resulting spatial clustering has a direct relationship with urban density and the predominant housing types in each part of the city. While 64.2% of the hot spots correspond to single-dwelling urban plots, 77% of cold spots match with multi-dwelling urban plots (Table 4). These results are similar to those obtained in other studies, in which a higher performance and water-saving potential are attributed to RWHS located in low-density urban areas [15,36]. The installation of rainwater tanks in single-family housing is easier and there are more potential uses–such as garden irrigation or car washing [47]. Nevertheless, there are single-dwelling plots that belong to a cold-spot cluster. In most cases, these residential plots correspond to old single-story buildings, with an average construction year between 1943 and 1953, located within the urban center and surrounded by apartment blocks. Likewise, it should be noted that there are many multi-dwelling residential plots included in the 99% confidence hot-spot cluster. However, not all multi-dwelling plots are apartment blocks. Some of these plots are semi-detached houses since the land registry information gives the same spatial reference to different single-family homes.

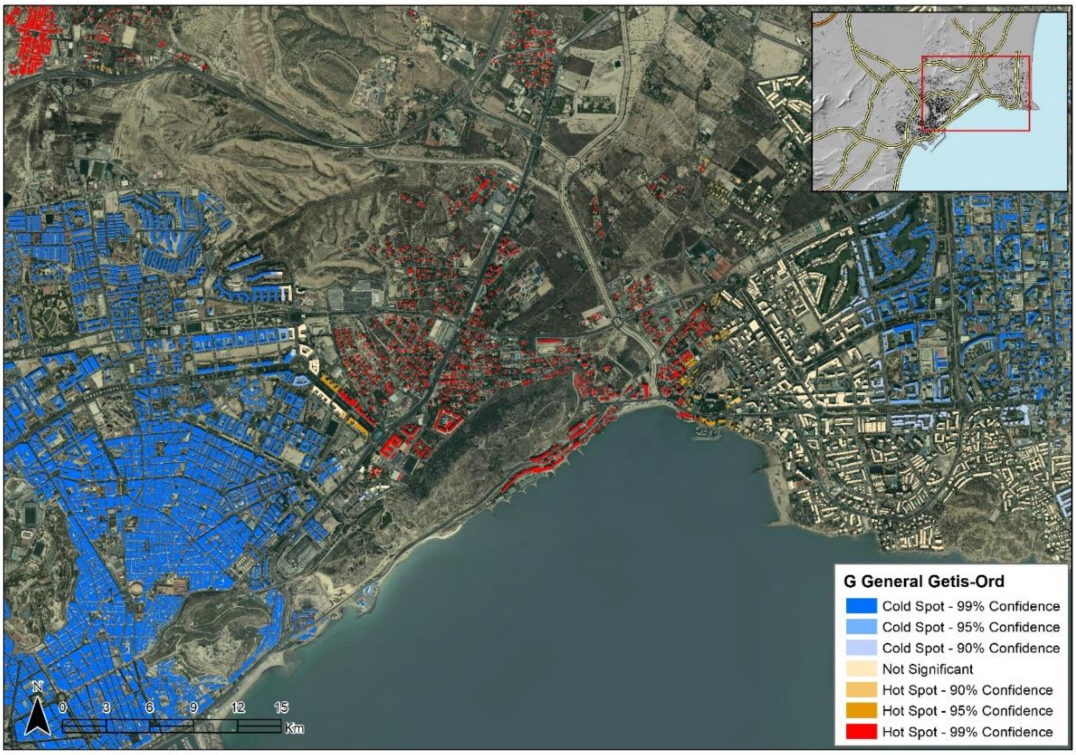

Figure 5. Detail view of the spatial distribution of the Getis-Ord general *G* statistic.

Table 4. Results of the Getis-Ord general G analysis according to type of building.

Type of Spots	Confidence	Residential Plots				RCHP [1]			
		Single-Dwelling		Multi-Dwelling		Single-Dwelling		Multi-Dwelling	
		n	%	n	%	m^3	%	m^3	%
Hot-spots	99%	2374	13.8	1397	8.1	87,619	7.6	88,759	7.7
	95%	335	2	145	0.8	9401	0.8	9980	0.9
	90%	160	0.9	53	0.3	4812	0.4	3792	0.3
Cold-spots	99%	2216	12.9	7418	43.2	62,836	5.4	596,560	51.7
	95%	88	0.5	284	1.7	3735	0.3	32,598	2.8
	90%	44	0.3	155	0.9	1873	0.2	33,125	2.9
Not significant		1175	6.8	1315	7.7	33,348	2.9	184,396	16

[1] Rainwater capture and harvesting potential.

It should be noted that most of the residential plots (59.5%) and most of the the city's RCHP (63.3%) are located in cold-spots. This fact is related to the predominant type of housing in the city, which are block buildings with multiple dwellings. This is evidenced by the inverse relationship established between the average number of inhabitants per building and the average RCHP per capita (Table 5).

In hot spots, fewer inhabitants per building are located, which results in a higher RCHP per capita, while the opposite occurs in cold spot. In summary, only 17.7% of the rainwater collection potential is located in hot-spot areas, where it is expected that the best performance of these infrastructures will be produced. Therefore, if there were a massive implementation of RWHS in the hot-spot areas of Alicante, there would be an RCHP of 204,365 m^3 for an average rainfall year. Thus, the theoretical water-saving potential would be reduced to 1.41%. This information may be of interest to local decision-makers for developing pilot rainwater harvesting implementation programs and for developing marketing strategies for companies that install these infrastructures. Furthermore, this methodology enables more realistic assessments of rainwater harvesting potential, since where there is low RCHP per capita, the installation of an RWHS should not be contemplated.

Table 5. Results of the Getis-Ord general *G* analysis according to inhabitants per plot and RCHP per capita.

Type of Spots	Confidence	Average of Inhabitants per Residential Plot	Average RCHP [1] per Capita (m^3)
Hot-spots	99%	8.07	11.22
	95%	10.57	8.67
	90%	8.83	9.31
Cold-spots	99%	36.02	4.93
	95%	48.08	6.10
	90%	71.31	6.78
Not significant		35.16	7.31

[1] Rainwater capture and harvesting potential.

4. Discussion

This research applies a new approach to the rainwater catchment assessment at the city scale through GIS techniques [15,24,25]. This methodology contemplates the identification of roof types through a supervised classification to distinguish the spatial distribution of runoff coefficients for each residential plot [40]. The results validate the method, since a good agreement was obtained between the sample of roof types and those obtained by the supervised classification (kappa index = 0.61). Few studies have so far considered the spatial variability of the runoff coefficient [6] and this study has made it possible to avoid an oversizing the RCHP–especially for flat roofs with asphalt sheets or gravel. The application of demographic disaggregation methods based on land registry data enables identifying the rainwater capture and harvesting potential (RCHP) per capita. The choice of this index is justified as it includes the most influential parameters in the performance of rainwater harvesting systems (RWHS) for the same climatic conditions: population density and roof size [36]. This methodology also enables the application of spatial clustering methods to facilitate the identification of the most suitable areas for the installation of these infrastructures at an urban scale, as well as offering more realistic estimates of the potential water savings derived from the large-scale installation of these infrastructures. This is particularly relevant in arid environments, such as Alicante, since rainfall patterns reveal unreliable rainwater supply. As has been evidenced in previous research, water savings derived from urban rainwater harvesting in semi-arid and arid environments show large variations depending on climate characteristics and social factors [25,30]. Likewise, the intensification of droughts in the Mediterranean countries with climate change is a factor that will increase the uncertainty of the performance of these infrastructures [48].

The results show that in most multi-family buildings in Alicante the installation of RWHS would not satisfy water basic uses such as the toilet flushing, with an average consumption per person of 24 L per day, or laundry, with an average consumption per person of 15 L per day [49]. This fact foreseeably limits the economic and environmental viability for the installation of RWHS to single-family houses since its higher roof area per capita enables greater water savings and rainwater, whose reliability in semi-arid climates is much lower, could satisfy non-essential uses, such as garden irrigation [50]. This issue is especially relevant as water savings together with capital and maintenance costs determine the length of pay-back periods [18]. However, RWHS installed in dense urban areas offer greater financial benefits, as a reduction of the amortization period produced because the initial investment is collectively paid [51]. Despite this, in multi-dwelling buildings, RWHS are usually designed before the construction of the building, so residents are usually unaware of its existence [18]. Furthermore, in technical terms, it is more difficult to install the infrastructure after the construction of a building and a financial commitment from all the residents in the property is also required. In any case, pay-back periods should be less than 40 years, which is the average life span of these infrastructures [18]. There are several factors that influence the profitability of the installation of rainwater harvesting systems, such as water demand patterns, the size of the rainwater tank and also water price [11]. The foreseeable increase in water prices in Mediterranean coastline municipalities, because of compliance with the cost recovery principle of the Water Framework Directive (WFD), will enable reducing the amortization period of RWHS. This is especially relevant in arid regions, where low rainfall patterns together with low water prices can make RWHS unviable without considerable water tariff increases [11]. This will occur especially among single-family homes, where there is greater water consumption and where a higher price of water is charged since the variable water service fee punishes high water consumption [49]. However, the assessment of these issues calls for precise knowledge of the water-saving produced by the introduction of rainwater when considering different rainwater end-uses, as well as various roof and tank sizes. Future research must focus on determine RWHS reliability of supply and performance on single-family homes in semi-arid environments, such as Alicante, through water balance simulation models and cost-benefit analysis.

5. Conclusions

The foreseeable reduction in available water resources and an intensification of droughts and floods owing to climate change may encourage local authorities to foster the development of RWHS [5]. In order to do so, a favorable urban policy context is one key aspect to promote sustainable urban settlements and favor the deployment of this infrastructure in urban environments [48]. While the acceptability of this infrastructure is generally high among the population [20,48], it is necessary to identify the most favorable areas for its installation in order to make investments profitable, especially in areas with a semi-arid climate, where the irregularity of rainfall decreases reliability and performance of this infrastructure. In this way the implementation of new regulations at the local scale to make these systems mandatory or ease its adoption through public subsidies may be more effective [10,18,48]. In Spain, in some areas with widespread implantation of domestic rainwater harvesting systems, it is usual that they have less than half year of rainwater availability and that garden irrigation is by far the largest use [48]. The main motivation indicated to install this infrastructure is usually related to environmental benefits, although in second place appears the economic issues [48]. In this respect, rainwater harvesting systems users felt moderate economic benefits, mainly due to insufficient precipitation, storage capacity for the harvested rainwater, which does not enable to harvest water in major rainfall events, and high installation cost [48]. In fact, in areas with a semi-arid climate, such as Alicante, the concentration of annual rainfall in few episodes, a pattern that is going to be exacerbated with the climate change, requires larger rainwater tanks capacity to minimize losses during intense rainfall events which would generate higher installation and capital costs. However, the gradually rising water prices that the Spanish Mediterranean coastline municipalities are experiencing, as a result of the introduction of desalinated water, the compliance of the Price Recovery principle of the WFD, among other factors, could make the use of harvested rainwater more economically viable.

Despite the traditional use of rainwater harvesting systems in Mediterranean Spain, currently only a few municipalities in the Barcelona area are supporting the installation of these infrastructures, as opposed to their widespread presence in other areas with similar climatic conditions, such as

California or Australia [16]. To foster its implementation, the promotion of its installation is needed, by mandatory means or promoted through subsidies. The results of this research can guide local regulation to require the installation of RWHS in new single-family homes and grant subsidies to facilitate the dissemination of these infrastructures [19]. Likewise, the link between areas with greater rainwater catchment potential, socio-economic level [27], and higher water consumption [49] justifies the installation of RWHS for environmental reasons and in terms of water justice. The development of RWHS in single-family dwellings would imply a fairer distribution of costs and reflect the greater pressure applied by such houses on water resources.

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