Water management assessment in a historic garden: the case study of the Real Alcazar (Seville, Spain)

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Abstract

Irrigation plays a very important role in a Mediterranean garden. In spite of this, there are not many studies assessing irrigation water management of landscapes. Moreover, historic gardens represent a special challenge due to their unique characteristics. The aim of this work is the characterization and evaluation of water management in a historic garden. For that, the gardens of The Real Alcazar of Seville were used as a case study. They comprise a total of 20 gardens of different styles with a total area of nearly 7 ha. Landscape water requirements and irrigation volume applied were estimated and used in conjunction with other descriptive and financial variables to calculate 6 performance indicators. Only 20 % of gardens showed adequate irrigation in the spring-autumn period, being 10 % during summer. However, the two well-watered gardens represent 30% of the total irrigated area. Management, operation and maintenance costs are 0.63 €·m^{-2} representing 0.58 € per volume of irrigation water used (m^{-3}). Results obtained support the need of improving irrigation management. For that, simple solutions such as installing metering devices, calculating actual water requirements or optimizing irrigation schedules can be implemented. Other more complex actions such as modifying the irrigation network or creating hydrozones might also be explored.

Keywords: irrigation; landscape; performance indicators; xeriscaping

1. Introduction

Green areas and gardens are ordinary urban landscape elements which provide many aesthetic and environmental benefits. They all have specific management and maintenance requirements such as pruning, pests and diseases control, fertilizing, infrastructures conservation or irrigation. However, historic gardens are less common and present several peculiarities which affect these tasks. ICOMOS IFLA (International Committee for Historic Gardens), in the Florence Charter (International Charter for the Conservation and Restoration of Monuments and Sites), defined the historic garden as "an architectural and horticultural composition of interest to the public from the historical or artistic point of view. As such, it is to be considered as a monument" (ICOMOS, 1982). ICOMOS emphasizes the role of water in the architectural composition of a historic garden. Hence, water represents an important element in garden design as it contributes to the feeling of freshness, and its sound and movement affects the senses (ICOMOS, 1982). In addition, in semiarid areas, irrigation becomes essential for the adequate vegetation development and appearance. Particularly, Mediterranean gardening is conditioned by an intense climatic stress and other environmental restrictions, such as rainfall seasonality and high temperatures in summer (Correia, 1993). The survival of plants in this environment is affected by abiotic stresses. Local species are best adapted to these conditions but also alien species from other areas with similar requirements can be artificially introduced (Niinemets and Peñuelas, 2008). Mediterranean gardens do not have a fixed structure and can present a wide range of combinations. The vegetation in these gardens used to be formed by trees that generate shaded areas (e.g. *Pinus pinea* and *Pinus sylvestris*), evergreen lush vegetation, or palm trees also tolerant to semiarid conditions (*Phoenix canariensis* and *Chamaerops humilis*). Trees or shrubs such as *Quercus ilex*, *Quercus suber*, *Laurus nobilis*, *Viburnum tinus* or *Nerium oleander*, and Mediterranean fruit trees (*Olea europaea*, *Citrus sinensis*, *Arbutus unedo* or *Punica granatum*) can also be found. Aromatic plants are usual for covering big areas, providing the Mediterranean garden with their characteristic smells and textures: *Cistus ladanifer*, *Rosmarinus officinalis*, *Lavandula angustifolia* or *Thymus vulgaris* (among others). The use of pergolas with climbing species is common in all the gardens styles emerged in the Mediterranean environment, and it is frequent to find species such as *Vitis vinifera* or *Jasminum officinale* which require warm conditions. All these species are adapted to low water and fertilization requirements, and consequently contribute to the principle of Xeriscaping. This concept combines a group of gardening techniques consisting in the implementation of water-saving guidelines (Smith and St. Hilaire, 1999). Originally, most Mediterranean historic gardens applied in some way Xeriscaping techniques (Wade et al., 2007).

The Real Alcazar of Seville (Spain) is one of the most emblematic monuments in the city, being an illustrative example of the different cultures stablished in Andalusia along different ages (Ruggles, 2008). The Alcazar finds its origin in the evolution that ancient Roman Hispalis experienced during the middle ages. It was at the beginning of the 10^{th} century, when the Caliph of Cordoba Abderramán III An-Nasir ordered the creation of a new building for the Government in 913 (Bosch Vilá, 1984). The Alcazar is a combination of palaces and gardens in which different architectural styles meet, from Mudejar to Gothic due to the historical evolution of the city in the last millennium (Blasco-Lopez and Alejandre, 2013). Its gardens and courtyards have always played a crucial role (Marín Fidalgo et al., 2015). Nowadays, they are composed by 176 different species of plants spread along 6.95 ha (Romero Zarco, 2004). This set of plants is the result of the natural and social interactions that have occurred during the ages. The Alcazar was declared "National monument" in 1931, and since then, all the historical set, including its gardens, is protected by the Spanish law (B.O.E., 1985). In addition, it was declared a World Heritage Site by UNESCO in 1987.

The unique set of historic gardens present in the Alcazar was built over a period ranging from the 12^{th} century until the 20^{th}. Due to their evolution over time, they exhibit a wide variety of styles, being considered as a living document of the history of gardening. However, this special uniqueness also hinders maintenance management and restoration and preservation tasks. A balance between the conservation of the historical essence of the gardens and the requirements for a daily use must be found. In the Alcazar, regardless of the historical period and style in which the gardens were created, most of the gardens have taken into account the Mediterranean climate in their design leading to the choice of many botanical species (with the possible exception of the Romero Murube´s landscape garden). In any case, irrigation is required in all of them. Traditionally, there was a gravity-based water distribution system using ditches and floodgates for surface irrigation which was changed in the 80s (20^{th} century) to a pressurized system, with a buried network of pipelines to enable the use of sprinkler and drip irrigation (Marín Fidalgo et al., 2015). These systems are supposed to be more efficient than surface irrigation in terms of water usage but this efficiency depends not only on the infrastructure but also on the management performed.

Water consumption in The Alcazar is relatively high, though not all of it is associated with irrigation and the supply of the palaces. Water has always had a remarkable presence from an ornamental point of view in the history of these gardens and also a large amount of this resource is used in the 74 fountains and 12 ponds scattered throughout these gardens. The hydraulic organ (The Fountain of the Fame), which uses water to produce its musical sounds, deserves a special mention.

Water management has become a main concern for the managers of The Alcazar gardens. In order to assess how water is used, there are different methods and tools. However, techniques widely used in agriculture are not yet widespread in gardening. There are few works addressing irrigation performance of landscapes (Fernández-Cañero et al., 2011; Haley et al., 2007; Hayden et al., 2015; Hof and Wolf, 2014; Salvador et al., 2011; Syme et al., 2004). Most of them are centered on water use assessment in terms of irrigation requirements or water consumption estimation. However, to our knowledge, no studies assessing water use and management in a historic garden have been performed so far. The objective of this paper is therefore to characterize and evaluate water management in The Alcazar of Seville, with special focus on the own particularities of a historic garden. For that purpose, the irrigation of the gardens was monitored during a complete year (2013).

2. Methods

2.1. Area description

2.1.1. Climatic characteristics

Seville has an altitude of 10 m above sea level and is located in the lower Guadalquivir valley, southwest of the Iberian Peninsula. Its Mediterranean climate is characterized by dry and warm summers and mild winters (Giorgi and Lionello, 2008). Rainfall concentrates in autumn and winter, with a mean annual record of 539 mm (1981-2010 year series). The marked seasonality of rainfall leads to periods of severe water deficit over the dry season (summer) (Fig. 1). All the climatic data used in this study has been obtained from the Seville airport's meteorological station (37.4166, -5.8791).

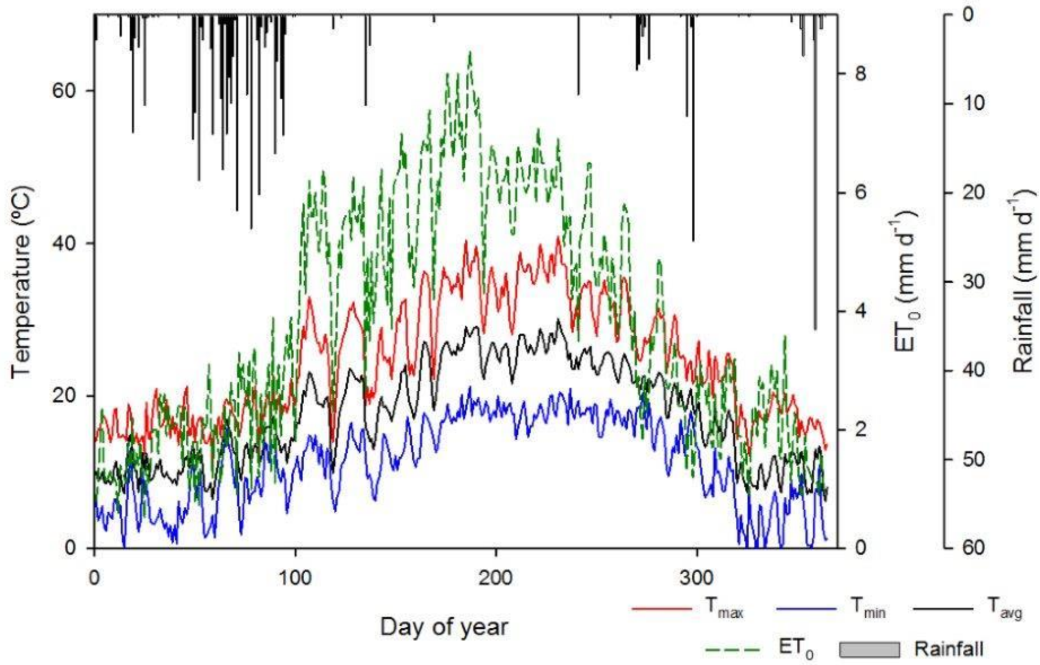

Figure 1. Rainfall (mm d^{-1}), ET_0 (mm d^{-1}) and temperatures (T_{max}, T_{min} and T_{avg}, ºC) during the year of the study.

2.1.2. Gardens of the Alcazar

The Alcazar is located in the center of Seville and comprises a combination of palaces and gardens (Fig. 2) with a surface area of 9.45 ha, of which 6.95 ha correspond to a total of 20 gardens which require to be irrigated from April to September. Being located in an alluvial plain of the Guadalquivir river (Borja and Barral, 2005), the Alcazar has a loamy soil with a high content of organic matter (Borja and Barral, 2002). The gardens have been classified (Table 1) according to the century of original construction and style (adapted from Blasco-Lopez & Alejandre, 2013; Marín Fidalgo et al., 2015; Tabales, 2005a, 2005b).

Figure 2. Selected gardens from the Alcazar. From left to right, up to down: The Courtyard of the Maidens, The Prince's Garden, The Flowers Garden, The Dance Garden, The Ladies´Garden, The Garden of the Alcove, The Maze garden, The English garden, and The Garden of the Poets.

Table 1. Gardens and courtyards of the Alcazar. Century of original construction (CoC); original styles: Almohad (A), Medieval (MV), Renaissance (R), Mannierist (MN), English (E), Romantic (R),

Contemporary (C) and Not defined (ND); type of irrigation (TI): hose (H), sprinkler (S), drip (D); and total (TA) and irrigated areas (IA).

Garden Code	Garden Name	CoC	Original Style	TI	TA (m^2)	IA (m^2)
1	The Courtyard of Plaster	XII	A	H	215.23	11.70
2	The Crucero Courtyard	XII	A	H-S	1387.60	622.78
3	The Courtyard of the Maidens	XIV	MV	S	600.81	216.50
4	The Ladies´Garden	XVI	R	H-S-D	4224.60	3006.20
5	The Prince's Garden	XVI	R	H-S-D	648.59	342.62
6	The Garden of the Alcove	XVI	R	H-S-D	4187.49	1634.78
7	The Garden of the Galley	XVI	R	H-S-D	361.48	163.99
8	The Dance Garden	XVI	R	H-D	817.23	412.27
9	The Alcubilla Courtyard	XVI	R	H	496.58	385.60
10	The Chorron’s Garden	XVI	R	H-S	249.23	122.07
11	The Levies, Romero Murube, and Assistant’s Courtyards	XVIII-XX	ND	H	455.53	47.20
12	The Flowers Garden	XVI	R	H-S	532.00	201.28
13	The Garden of Troy	XVI	R	H	284.01	20.20
14	The Hunting Courtyard	XX	ND	H	1632.55	331.38
15	The Courtyard of the Lion	XX	ND	H-D	948.98	418.16
16	The Garden of the Cross	XVII	MN	H-S-D	2180.55	883.66

17	Orchards	XIX	ND	H-S-D	10902.64	7236.19
18	The Garden of the Marquis of Vega Inclán	XX	C	H-S-D	15863.62	9293.04
19	The English Garden and The Maze Garden	XX	E-ND	H-S-D	18504.15	12659.08
20	The Garden of the Poets	XX	R	H-S-D	3997.17	1651.70

2.1.3. Infrastructures for irrigation

Irrigation in The Alcazar has evolved over time. In the last two centuries, the main water supply was provided through Los Caños de Carmona (Roman aqueduct) (Fernández Chaves, 2011) and wells located in The Alcazar. Several ponds (e.g. Pond of the Lion) were used to store water for irrigation (Baena Sánchez, 2003). Traditionally, there was a gravity-based water distribution system using ditches and floodgates for surface irrigation. The gardens still maintain the slope of the ancient surface (i.e. border and furrow) irrigation system. Water was delivered to the different gardens by means of a network of open channels, still preserved nowadays.

Currently, irrigation water is supplied only by three wells and the Pond of Mercury. Each well supplies water to part of the gardens. Therefore, three irrigation sectors are formed (see Interactive Map). A pipeline network is used to distribute water by gravity from the higher areas, to the rest of the gardens (Cómez Ramos, 1993). These pipes are interconnected, and also linked to the wells and the water tank. A new network of secondary pipes for drip and sprinkler irrigation was installed in 1990.

The Well of Troy (W_T) provides water for the Almohad and Renaissance gardens such as the Courtyard of Plaster and the Ladies' Garden. The English Garden and the Garden of the Alcove are irrigated with water obtained from the Well of Carlos V (W_{CV}). The Well of Grapevine (W_G) supplies water to the rest of modern gardens. The Pond of Mercury is located at the same height of the palace, 15 m above the lower gardens. Three types of irrigation systems are currently used in The Alcazar: drip, sprinkler and manual flood irrigation with hose in small basins. The irrigation area is divided according to the above mentioned sectors. Flood irrigation with hose is used as a complementary water supply for the flower beds that lack of drip or sprinkler irrigation systems. All hydrants for the hose are placed 30 m apart from each other, such that a 15-meter long hosepipe may carry water to any point of the garden.

Sprinkler irrigation is the most widespread system in The Alcazar, used in a large number of gardens normally to irrigate the area surrounded by the flower beds. There are two types of sprinklers with a flow rate of $1.77 \cdot 10^{-4}$ and $1.47 \cdot 10^{-4}$ $m^3 \cdot s^{-1}$. Drip irrigation is used to irrigate (i) the hedgerows that border the flower beds in most of the gardens, (ii) the rose gardens and (iii) the Maze Garden. For that, three type of non-pressure compensating emitters are used with flow rates ranging between 2 and 4 $l \cdot h^{-1}$. The uniformity of drip irrigation was assessed in three gardens by calculating the Distribution Uniformity (DU) (Keller and Bliesner, 1990), defined as the average water applied by the 25% of emitters supplying the least amount of water divided by the average water supplied by all sampled emitters of a certain garden. At least ten emitters located in initial, medium and final laterals of the sub-main were sampled in each garden. An average DU of 80% was obtained in the three analyzed gardens.

2.2. Landscape water requirements

Water requirements for the different gardens have been estimated following the WUCOLS procedure described in Costello, Matheny, & Clark (2000). Nouri, Beecham, Hassanli, & Kazemi (2013) established that the WUCOLS method was more reliable than others for estimating the water requirements of mixed vegetation in urban landscapes. Therefore, Landscape Evapotranspiration (ET_L, mm·month^{-1}) is calculated monthly as:

$$ET_L = K_L \cdot ET_o$$

where ET_o is reference evapotranspiration (mm· month^{-1}) and K_L is a landscape coefficient. ET_o is used as a measure of the climatic water demand on landscapes and agricultural crops which has been determined according to the FAO Penman-Monteith method (Allen et al., 1998) .

K_L is used to compute standard landscape evapotranspiration (ET_L) and depends on several factors: plant species, vegetation density and microclimate (Costello et al., 2000). It is therefore calculated as the product of three coefficients:

$$K_L = K_s \cdot K_d \cdot K_{mc}$$

where K_s is defined as Species Coefficient, and its value is basic to determine K_L. However there is not a standard list of K_s values, so most gardening professionals must trust on their own judgment and experience to set the value of this coefficient for their particular climate and local conditions. In this study, the K_s values suggested by Costello et al., (2000) were used (Annex A). For each garden, an average value of K_s is set taken into account all the plants present. K_d is the Coefficient of density whose value may vary within the range 0.5-1.3, the greater the value the denser the garden. Gardens differ considerably in terms of their vegetation densities. For instance, young gardens or with sparse vegetation have lower leaf area than dense or mature gardens. For calculating the value of K_d the type of vegetation (trees, shrubs, ground cover, mixed planting or lawn) present in each garden is considered (Ávila Alabarces et al., 2004; Costello et al., 2000).

K_{mc} is the Coefficient of Microclimate (Costello et al., 2000) which takes into account the existing microclimatic differences among gardens, such as those due to nearby buildings and paving, wind speed, light intensity and humidity (Ávila Alabarces et al., 2004).

Once ET_L has been determined, net irrigation water requirements (IR_N, mm) are calculated monthly as follows:

$$IR_N = ET_L - P_e$$

where P_e is effective rainfall, assumed to be 75 % of total rainfall. In the absence of risk of soil salinization, gross irrigation water requirements (IR_G, mm) are computed as:

$$IR_G = \frac{IR_N}{E_a}$$

where E_a denotes the irrigation efficiency, considered to be 85 % in drip irrigation systems, 75% in sprinkler irrigation and 60 % for hose-watered areas (Ávila Alabarces et al., 2004).

2.3. Estimated irrigation volume

The volume of irrigation water applied in each garden (I) has been calculated over a whole irrigation season (from mid-April until the end of September 2013). In the absence of measuring devices (flow meters), water applied was estimated from the product of total flow rate installed for each irrigation system and the operation time.

Total flow rate per irrigation system was determined for each individual garden by inventorying the number and type of emitters, in the case of drip and sprinkler irrigation. When using a hose for irrigation, the discharge rate was repeatedly measured and a mean value of $1.56 \cdot 10^{-3}$ $m^3 \cdot s^{-1}$ has been finally used for calculations. The operation time for each irrigation system was monitored in all the gardens throughout the irrigation season. For that, given that automated irrigation programmers are not used, the weekly schedule to manually open and close irrigation sectors as well as field observations were taken into account.

The gardens are watered twice or three times a week, depending on the season of the year, with sprinklers and drip emitters. In the areas manually irrigated by hose, the gardener performs a weekly circuit so plants are watered at least once a week over the irrigation season. Irrigation scheduling is not scientifically-based but decisions are taken by the personnel of the garden in a somewhat arbitrary and empirical way.

2.4. Performance indicators

Performance indicators are a useful tool for easily evaluating the effectiveness of irrigation management (Alegre et al., 2000). The International Programme for Technology and Research in Irrigation and Drainage (IPTRID) compiled and developed a series of performance indicators for irrigation management (Malano and Burton, 2001). They have been widely used in agriculture in order to assess water management, having shown good results (Rodríguez-Díaz et al., 2008). The performance indicators employed in this research were calculated as detailed in Table 2.

Table 2. Performance indicators used and their equation

Indicator	Equation
Relative Water Supply (RWS)	$\mathrm{RWS} = (\mathrm{I} + \mathrm{P}_e)/\mathrm{ET_L}$
Relative Rainfall Supply (RRS)	$\mathrm{RRS} = \mathrm{P}_e/\mathrm{ET_L}$
Relative irrigated Area (RA)	$\mathrm{RA} = \mathrm{IA}/\mathrm{TA}$

Total MOM cost per unit area (MOMa) (€·m^{-2})	$MOMa = MOM\ cost/IA$
Total MOM cost per unit volume supplied (MOMv) (€·m^{-3})	$MOMv = MOM\ cost/I$
Labor per unit area (PA) (person·ha^{-1})	$PA = NW/TA$

I (mm): irrigation depth; P_e (mm): effective rainfall; ET_L (mm): Landscape Evapotranspiration; IA (m^2): irrigated area; TA (m^2): total area; MOM cost (€): management, operation and maintenance costs; NW (persons): number of workers.

RWS provides information about the shortage or excess in the water supply (Molden and Gates, 1990). RWS is the ratio between the volume of water applied and the amount of water needed for proper plant development (Levine, 1982). A similar indicator was used by Salvador et al. (2011) to assess irrigation performance in private urban landscapes. RRS shows the fraction of landscape water requirements covered only by rainfall (Pérez Urrestarazu et al., 2009). This indicator complements the information obtained by RWS and will have the same value if no irrigation takes place. RA is the ratio between the surface that is irrigated in each garden and its total area. This indicator is interesting in gardening because the irrigated surface differs from the total area depending on the type and structure of the garden or courtyard. Management, Operation and Maintenance (MOM) costs were calculated based on the irrigated area and the volume of water applied (Rodríguez-Díaz et al., 2008). Only the costs related to irrigation operations were taken into account.

3. Results

Gross water requirements (IR_G) were estimated monthly for each garden. Table 3 presents the average IR_G values for two different periods, spring-autumn (May and September) and summer (June, July and August). Monthly irrigation volumes supplied with each method were also calculated for each garden. Average values for the spring-autumn and summer periods are presented in Table 3. The amount of water supplied with hose and drip irrigation was very similar in all months, since the personnel with irrigation functions established the same irrigation schedule for these two irrigation systems throughout the irrigation season, irrespective of the changing crop water demand. This was not the case of sprinkler irrigation, whose water supply was more variable depending on the period. Total volume of water applied in each garden is also shown.

Table 3. Irrigation supply per method and irrigation requirements (IR_G) in each garden (Garden No. corresponds to the number assigned to each garden in Table 1)

Garden No.	Irrigation Volume (mm·month^{-1})				Total volume (mm·month^{-1})		IR_G (mm·month^{-1})	
	Hose	Drip	Sprinklers					
			Spring-Autumn	Summer	Spring-Autumn	Summer	Spring-Autumn	Summer
1	29.91	-	-	-	29.91	29.91	43.91	98.97
2	29.93	-	131.54	164.42	161.47	194.35	82.11	142.80
3	-	-	158.15	197.69	158.15	197.69	26.82	86.34
4	24.85	140.09	89.42	134.12	254.35	299.06	39.76	83.47
5	22.59	95.67	89.66	112.08	207.93	230.34	70.77	125.47
6	24.84	94.90	113.53	136.24	233.27	255.98	34.87	77.50
7	24.84	214.78	208.79	260.99	448.42	500.62	38.65	83.75
8	24.84	377.83	-	-	402.67	402.67	42.97	86.08
9	29.93	-	-	-	29.93	29.93	75.73	142.06
10	29.90	-	211.02	263.78	240.92	293.68	46.19	94.30
11	22.67	-	-	-	22.67	22.67	81.36	149.69
12	24.84	-	257.56	321.95	282.40	346.79	24.53	65.73
13	24.75	-	-	-	24.75	24.75	87.09	157.45
14	29.94	-	-	-	29.94	29.94	98.00	172.22

15	29.94	178.69	-	-	208.63	208.63	31.16	70.08
16	9.28	91.04	86.91	101.40	187.23	201.72	36.43	78.96
17	1.91	25.67	47.89	71.84	75.47	99.41	47.24	92.22
18	20.17	217.05	15.98	23.97	253.19	261.18	57.48	107.47
19	9.27	57.80	27.10	60.97	94.17	128.05	35.02	77.78
20	49.73	11.53	16.27	24.41	77.54	85.68	61.90	115.43

RWS and RRS have been calculated for each garden from May to September (Table 4), using the information provided in Table 3. Given the amount of data obtained, RWS values were divided into three categories: a RWS below 0.7 was considered deficit irrigation while values exceeding 1.5 were established as excessive. Based on the existing uncertainty on the theoretical estimation of landscape water requirements, the range between 0.7 and 1.5 was defined as correct. Following these criteria, only 20 % of gardens present adequate irrigation in the spring-autumn period, whereas this value decreased to 10 % during summer. Five gardens (1, 9, 11, 13, and 14) show deficit irrigation (1 and 9 only in summer), receiving in some cases three times less water than required. Most of the gardens present excessive watering, with RWS values well above 1.5. For example, 7, 8 and 12 received up to seven times more water than required in the spring-autumn period. In this period, the tendency to over irrigate is more patent probably because rainfall is not taken into account when estimating irrigation needs and hence the total water volume applied is excessive. Most gardens are also irrigated in excess during summer. Only two gardens (18 and 20) show a correct irrigation with RWS close to 1. However, these two gardens represent 30% of the irrigated area in the Alcazar. Garden 1 also has adequate irrigation during the spring-autumn period. RRS values clearly show that irrigation must cover most of the water requirements in all cases during summer (especially in July and August). However, in Spring-Autumn, a great percentage of requirements are satisfied by rainfall (in many cases, more than 50 %).

There are some gardens and courtyards in which the irrigated area is minimal, corresponding to low RA values (e.g.: 1, 11, 13, 14). In these cases, hose watering is the most common method. Garden 9 is the exception as it is irrigated by hose but has the highest RA.

Table 4. Relative irrigated Area (RA), Relative Water Supply (RWS) and Relative Rainfall Supply (RRS)

Garden No.	RA	RWS					RRS				
		May	**June**	**July**	**August**	**September**	**May**	**June**	**July**	**August**	**September**
1	0.05	1.11	0.67	0.45	0.54	1.05	0.51	0.16	0.02	0.07	0.39
2	0.45	2.15	1.97	1.6	1.78	2.27	0.29	0.09	0.01	0.04	0.22
3	0.36	5.13	4.88	3.97	4.41	5.43	0.71	0.23	0.03	0.10	0.54
4	0.71	4.98	4.63	3.81	4.22	5.35	0.45	0.15	0.02	0.06	0.34
5	0.53	2.85	2.47	2.02	2.24	3.04	0.31	0.10	0.01	0.04	0.24
6	0.39	4.11	3.55	2.91	3.23	4.4	0.40	0.13	0.02	0.06	0.31
7	0.45	7.52	6.83	5.68	6.26	8.18	0.40	0.13	0.02	0.06	0.31
8	0.50	7.13	5.79	4.8	5.30	7.74	0.42	0.14	0.02	0.06	0.32
9	0.78	0.79	0.48	0.32	0.38	0.75	0.36	0.12	0.01	0.05	0.28
10	0.49	4.54	4.36	3.59	3.97	4.87	0.43	0.14	0.02	0.06	0.33
11	0.10	0.65	0.37	0.23	0.29	0.6	0.35	0.11	0.01	0.05	0.26
12	0.38	7.34	7.16	5.92	6.54	7.9	0.61	0.20	0.02	0.08	0.46
13	0.07	0.65	0.38	0.24	0.3	0.61	0.33	0.11	0.01	0.04	0.25
14	0.20	0.66	0.4	0.27	0.32	0.62	0.30	0.10	0.01	0.04	0.23
15	0.44	4.66	3.66	2.98	3.31	4.97	0.51	0.16	0.02	0.07	0.38

16	0.41	4.01	3.36	2.73	3.04	4.27	0.48	0.15	0.02	0.07	0.36
17	0.66	5.46	4.53	3.74	4.13	5.9	0.40	0.13	0.02	0.06	0.30
18	0.59	1.33	1.15	0.87	0.99	1.32	0.41	0.13	0.02	0.06	0.31
19	0.68	2.29	2.22	1.77	1.98	2.36	0.49	0.157	0.02	0.07	0.37
20	0.41	1.45	1.13	0.87	0.99	1.48	0.36	0.115	0.01	0.05	0.27

MOM costs are 0.63 €·m^{-2} and 0.58 €·m^{-3} referred to area unit (MOM_a) and volume of water supplied (MOM_v) respectively. Eleven percent of the total staff cost is dedicated to irrigation functions. The number of persons involved in tasks related to water management per irrigated area (PA) is considerably high (5.52 person·ha^{-1}) and 13% of the total hours of work in the gardens are devoted to irrigation. This is probably due to the lack of planning and automation of garden duties and the costly irrigation by hose for flower beds.

4. Discussion

Water management has shown to be inadequate in most of the studied gardens according to the RWS values obtained (Table 4). This is consistent with the results found by other authors which have pointed out that low irrigation efficiency and uniformity and excessive water applied is very common in gardening (Fernández-Cañero et al., 2011; Haley et al., 2007; Nouri et al., 2013; Parés-Franzi et al., 2006; Salvador et al., 2011). For example, Parés-Franzi et al. (2006) evaluated the irrigation performance of 106 urban parks in the Barcelona metropolitan region, finding that in only 13.2 % of them irrigation was adapted to plant water requirements. In our study, most of the gardens of The Alcazar had excessive watering, a few of them with unacceptable high RWS values. The gardens showing deficit irrigation were those irrigated only by hose which points to be the main reason for being under irrigated. Some other authors have also reported that using hose for irrigation usually leads to lower volumes of water applied than when employing other systems (Domene et al., 2005; Endter-Wada et al., 2008; Mayer et al., 1999). Except when watering by hose, no correlation was found between irrigation adequacy and irrigation method which means that, in this case, drip irrigation did not stand out as a more efficient system in terms of water use.

The reasons for over-irrigation may be multiple. Firstly, we face the wrong belief of having water free of charge when water is pumped from wells and that the excess water is not wasted as part of it recharges the aquifer. But this way of thinking involves an irresponsible use of natural resources that may contribute to groundwater contamination and increases MOM costs. In this case, the reuse of water is possible because it comes from wells located in The Alcazar and it is usually available at demand. Also, the only variable costs assigned to the amount of water used are the energy costs, but they represent a low portion of total costs. This means that water can be considered cheap if indirect costs, such as environmental impacts, are not taken into account. Likewise, this excess of watering may also be motivated by the pressure to have healthy looking plants, giving more importance to aesthetics than to a rational use of resources. But aesthetically pleasing landscapes should not exclude a water-efficient performance (St. Hilaire et al., 2008). There are many water conservation management practices that can help optimizing water use, though managers are usually reluctant to apply them because they think they may compromise aesthetics (Hayden et al., 2015). These best management practices (BMP) such as planting species with low water requirements or adjusting automatic irrigation systems to avoid overwatering are relatively easy to implement (Hayden et al., 2015).

Surprisingly, as in this case study occurs, the lack of automated irrigation with no available programmers is very usual in gardens (Fernández-Cañero et al., 2011; Parés-Franzi et al., 2006). For instance, the implementation of a centralized irrigation system with a main computer would permit fast adjustments in each of the 24 different gardens, precise application of water, full knowledge of the exact water volume used, alert messages for leakages, etc. That would contribute to attain a better irrigation scheduling, achieving at the same time a reduction in MOM costs. In fact, the MOM costs calculated are very high compared to those obtained in agriculture irrigation in southern Spain (Rodriguez-Díaz et al., 2012; Rodríguez-Díaz et al., 2008). Not much information on costs has been found in gardening. As an example, Arbat et al. (2013) analyzed nearly 500 private gardens in two Spanish cities, obtaining a range of MOM_a costs between 0.12 and 1.62 €·m^{-2}. In the case of The Alcazar, energy only represents 4% of total costs, a very low value considering that Arbat et al. (2013) observed a range of 3.5-22.8 % of energy over total costs. Therefore, most of these costs are due to personnel.

The use of water flow meters is essential for an optimum irrigation management as, otherwise, water leakages or other failures in the irrigation network, as well as an incorrect operation of the system, may lead to an indiscriminate use of resources while these problems are not detected. Hence, installing metering devices could be a simple and low cost measure to help in irrigation management decisions. Also, water application technologies such as controllers that schedule irrigation based on environmental conditions and soil moisture sensors can improve water management decisions (St. Hilaire et al., 2008). As an example, Parés-Franzi et al. (2006) observed that irrigation of most urban parks in Barcelona was not modified based on real-time climatic conditions, particularly rainfall events, which resulted in a less accurate water management plan. Managers should seriously consider adopting these technologies as part of their long-term landscape irrigation plans. In addition to identifying the level of uniformity required and using efficient water application systems, irrigation schedules based on actual climatic and soil moisture content should be accurately determined (St. Hilaire et al., 2008). An adequate irrigation schedule requires an updated knowledge about the water needs of the different areas and gardens in order to perform a correct water balance by considering P_e, ET_L and the water holding capacity of the soil (Smith, 2000). This watering schedule should be flexible enough to program irrigation events according to the climate variability. In fact, usually, when RRS is high, also RWS is excessive which means irrigation should be radically reduced because rainfall provides part of the water required. It is important to note that run off coming from impervious surfaces (paths, pavements and other hard surfaces) was not taken into account in this study. Therefore, RRS values may be even higher in some gardens especially those with lower RA. Precisely, the oldest gardens tend to have less RA than Modern or Renaissance gardens. This is because the Historical and Spanish-Arabian gardens are usually tiled courtyards. As an example, the most modern garden, the English Garden, has 14 times more RA than the oldest, The Courtyard of Plaster (0.68 and 0.05 respectively), which is an Almohad garden. Most of Spanish-Islamic gardens are usually courtyards with fountains in the center, contrasting with the open, grassy structure of the English landscape garden, frequently associated with a significant water consumption that can be critical when the garden is located in the Mediterranean area.

The design of the garden and location of species from the water management point of view also plays an important role. In most cases, the irrigation sectors seem to be poorly designed. Species with different ranges of K_s are present in the same parterre or areas, not considering hydrozones, i.e. zones with species requiring similar water needs. The irrigation management of mixed vegetation is a challenge because there are species with different capacities for water acquisition and water requirements (Chaves et al., 2002). This problem is common in historic gardens, where exotic and non-native species with high water requirements (e.g. *Monstera deliciosa, Colocasia esculenta, Musa paradisiaca,* and others) have been introduced in successive interventions throughout the centuries (Cabeza Méndez, 2009). Historical, Landscape Heritage and Sustainability criteria should be reconciled for future restoration or replacement of diseased species. The selected plantations must combine low water requirements, sustainable maintenance, great adaptation to local conditions, conserving at the same time the historical identity of the Alcazar and monumental landscape integration with the environment (attractive color, shape and texture dynamic) (Smetana and Crittenden, 2014). Non-native ornamental species should be only used in small number, not as major garden components (Kümmerling and Müller, 2012). Besides, the presence of two or three different irrigation methods in some sectors is not justified and involves greater MOM costs. Some areas receive water both from drippers and sprinklers which complicates to supply the correct amount of water when both irrigation systems are sourced by the same pipelines. However, in most situations such as in this case study, modifying the existent irrigation network or the configuration of the hydrozones is a complex and costly solution that not always can be easily implemented.

The establishment of adequate maintenance protocols of the irrigation infrastructure can be another action that also contributes to optimize water management. In this particular case study, no maintenance protocols for the irrigation facilities were established, resulting in unidentified clogged drip emitters or inadequate mixture of both types of sprinklers used within the same irrigation unit. This may lead to poor water distribution uniformities and thus to poor water use efficiencies (St. Hilaire et al., 2008), so an appropriate maintenance protocol should also be established in landscape irrigation.

5. Conclusions

This study provides, to our knowledge, the first attempt to evaluate water management of an historic garden, The Real Alcazar of Seville. This garden is particularly relevant in terms of its historic and aesthetic value, its size and the fact that is located in a water-limited region. The analysis of irrigation water management has been carried out through performance indicators, widely used in agricultural studies, but inexistent in landscape irrigation management assessments. This study is an example of how these performance indicators can be suitably adapted also for garden and landscape irrigation. Overall, most of the gardens of The Real Alcazar presented water deliveries well above their actual water requirements. The performance indicators also show that, during spring-autumn months, rainfall could cover most of the gardens' water requirements, but this water input was not or little considered in irrigation scheduling, thus contributing to the high levels of over-irrigation observed in some of the gardens. The Management, Operation and Maintenance (MOM) costs associated to garden irrigation were also high as compared to those obtained in agriculture irrigation. These findings reveal that there is still much room for improvement in irrigation management of urban landscapes, with special emphasis in historic gardens with great aesthetic value that predominates over the efficient use of resources. For that, simple solutions such as installing irrigation programmers and metering devices or improving irrigation schedules taking into account actual water requirements can be implemented. Other actions like modifying the irrigation network or sectorizing according to the determined hidrozones are more complex and involve a greater effort, but would have a greater impact on an optimized water management.

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