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Water requirements of urban landscape plants in an arid environment: The example of a botanic garden and a forest park

Paria Shojaei[a], Mahdi Gheysari[a,*], Hamideh Nouri[b], Baden Myers[c], Hadi Esmaeili[a]

[a] Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran
[b] Faculty of Engineering Technology, University of Twente, Netherlands
[c] School of Natural and Built Environments, University of South Australia, SA, Australia

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ABSTRACT

Creation and conservation of urban parks is challenging in arid environments where daily thermal extremes, water scarcity, air pollution and shortage of natural green spaces are more conspicuous. Water scarcity in the arid regions of Iran is major challenge for water managers. Accurate estimation of urban landscape evapotranspiration is therefore critically important for cities located in naturally dry environments, to appropriately manage irrigation practices. This study investigated two factor-based approaches, Water Use Classifications of Landscape Species (WUCOLS) and Landscape Irrigation Management Program (LIMP), to measure the water demand of two heterogeneous urban landscapes: a botanic garden and a sparse forest park. The irrigation water volume applied was compared with the gross water demand for the period from 2011 to 2013. In this research, WUCOLS estimated the annual water requirement of a botanic garden and a sparse forest park to be 5% and 44% lower, respectively, than LIMP. Comparison of estimated and applied irrigation showed that water savings can be made by the LIMP method. The outcomes of this research stressed the need to modify the irrigation requirements based on effective rainfall throughout the year, rather relying on long-term average data.

1. Introduction

The constructive influences of green spaces on quality and liveability of the urban environment have been reported in many studies (Amiri et al., 2009; Jansson, 2006; Kottmeier et al., 2007; Ozdogan et al., 2010; Petralli et al., 2014; Robitu et al., 2006). These effects can be more manifested in an arid urban environment because there is a more prominent pattern of daily thermal extremes (Pearlmutter et al., 2007), and also an interaction between high air pollution levels and minimal rainfall in such climates (Rosenfeld, 2000). In arid urban climates, vegetation cover can mitigate the urban heat island effect (Takebayashi and Moriyama, 2007), enhance thermal comfort (Petralli et al., 2015) and reduce air pollution (Edem et al., 2014). Generally, there is a shortage of green spaces in an arid urban environments due to low mean annual rainfall which often leads to a high albedo, strong wind and frequent sand or dust storms (Pearlmutter et al., 2007). Therefore, creation, conservation and management of urban green spaces in arid regions are necessary in order to modify the urban energy balance. The evapotranspiration is an important factor affecting the vitality and performance of urban green spaces (Marasco et al., 2015).

Iran has a spatially variable climate ranging from arid to extra arid in the east and central parts, semi humid to per-humid in the southern coastal plains of the Caspian Sea, Mediterranean to humid in some areas in the west, and semi-arid over the rest of the country (Rahimi et al., 2013). Isfahan is a city located in the center of Iran and has a dry climate. The mean annual precipitation is 122 mm, (based on 30 years of precipitation records collected by the Iran Meteorological Organization), with no rainfall in summer (20th Jun to 20th Sep). The mean annual potential evapotranspiration is about 1600 mm (Dinpashoh et al., 2011; Tabari et al., 2011), which is about 13 times larger than of the annual rainfall. Therefore, there is intense competition between water users for the limited water resources. Since human activities are constrained by limited supplies of water, managing urban ecosystem services involves trade-offs among alternative uses (Häyhä and Franzese, 2014). A severe shortage of surface water resources in Isfahan has caused over-consumption of ground water and a significant decline in the water table. This has created irrecoverable environmental problems. Under such circumstances, the deficit in water supply in Isfahan city is one of the most prominent challenges faced by managers and decision makers.

The total area of green cover in Isfahan is 5459 ha (Isfahan Municipality; 2017). Therefore, landscape irrigation is one of the main

* Corresponding author at: Department of Water Engineering, College of Agriculture, Isfahan University of Technology, 84156-83111 Isfahan, Iran.
E-mail address: Gheysari@cc.iut.ac.ir (M. Gheysari).

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users of urban water resources. The local government has a strong focus on finding strategies to better manage limited water resources for green space irrigation. At the present time, there is no regulated procedure to calculate the landscape water requirement in Isfahan. An efficient and feasible method for estimating the landscape water requirement is therefore needed, which can take into account unique local conditions in the urban landscape.

Different methods for estimating the water requirement of heterogeneous urban landscape was discussed by Nouri et al. (2013d). The advantages and disadvantages of each method was comprehensively deliberated. There are numerous challenges in estimating landscape evapotranspiration in an urban environment compared to an agricultural field including the heterogeneous plants, the presence of vegetation in small and isolated parcels, the presence of various microclimates in urban areas (Costello et al., 2000). Furthermore, the goal of water requirement estimation for an urban landscape is different to a conventional agricultural site as the landscape water demand is estimated to maintain optimal growth, health and aesthetic appearance rather than biomass and yield production which is the case in agriculture. As such, landscape plants may be irrigated less than agricultural crops (Allen et al., 2011).

There are some factor-based methods that assign a variety of different coefficients in order to reflect all of these effects on water demand of urban landscapes such as the Water Use Classification of Landscape Species (WUCOLS) (Costello et al., 2000), the Landscape Irrigation Management Program (LIMP) (Snyder, 2010; Snyder and Eching, 2005) and the plant factor method (PF) (South Australian Water Corporation-IPOS Consulting, 2008).

The goal of this study was to estimate the urban landscape water requirements of an arid region to evaluate whether current design and management practices in Isfahan city may be considered sustainable irrigation in light of the ongoing concern of water resources. Two factor-based ET estimation methods of urban vegetation, namely WUCOLS and LIMP are applied to estimate the urban landscape water requirements of two green spaces in Isfahan city. The water requirement estimations by these two methods were compared to the amount of water applied in practice. The results of this study will be important for decision makers in all arid urban environments where creation and conservation of urban green spaces must be weighed against the need to conserve limited water resources.

2. Methods and data

In this study, the water requirement of two urban green spaces (ET_l) was estimated using two factor-based methods of WUCOLS and LIMP during the years of 2011, 2012 and 2013. The regional reference evapotranspiration (ET_0) was estimated using the Valiantzas expression based on the meteorological data from the Research Centre for Atmospheric Chemistry, Ozone and Air Pollution in the Isfahan province. The environmental conditions of regional meteorological station was not in accordance with the standard environmental condition for ET_0 estimation. Therefore, we used Annex 6 of FAO-56 to adjust weather data in a non-reference site to reflect standard reference conditions (Allen et al., 1998). The air temperature and relative humidity of two study sites were collected to estimate ET_{0l}. Finally, the gross irrigation water requirement was estimated and compared with the amount of water applied in practice.

2.1. Site description

This study was conducted in Isfahan city (Latitude: 32°36′ to 32°43′ N, Longitude: 51°36′ to 51°43′), located in the center of Iran. (Fig. 1(a)). Isfahan has a cold and arid climate based on the Köppen Climate Classification System (Geiger, 1961), with an average annual temperature of 17 °C. In summer (20th June to 20th September), the average temperature is about 28 °C with no rainfall. In winter (20th December to 20th March), the mean temperature is approximately 5 °C (based on 30 years of precipitation records by the Iran Meteorological Organization).

Two public parks in Isfahan were selected as study area namely Golha (a botanic garden) and Fadak (a sparse forest park) (Fig. 1). Golha Garden with an area of 8 ha is located in the city centre and contains over 200 plant species. In the north and west side of Golha Garden, the green cover changes to an impervious street surface with a high volume of vehicular traffic and dense housing coverage. The south side of the garden meets the Zayandehrod River, which was dry during 29 months out of 36 months of the measurement period. The east side of Golha Garden is covered by similar green landscape. Fadak Park has an area of 75 ha and is located in the north east of the city. It has about 20 tree species, mostly conifers, which are resistant to drought. Fadak Park is surrounded by bare land and residential buildings in the east, south and west. A majority of land use in the north side of Fadak Park is agricultural.

Golha Garden uses a showerhead hose irrigation method, while Fadak Park uses drip tape for trees and showerhead hose irrigation for turf grass.

2.2. Water use classifications of landscape species method

The WUCOLS method was described by Costello et al. (2000) to estimate the water requirement of mixed urban vegetation while maintaining acceptable appearance, health, and reasonable growth. This method has been used in several urban studies (Cubino et al., 2017; Hof and Wolf, 2014; Nouri et al., 2016; Parés-Franzi et al., 2006; Reid and Oki, 2016; Salvador et al., 2011). Using the WUCOLS approach, the landscape evapotranspiration (ET_L) is calculated as shown in Eq. (1):

$$ET_L = ET_0 K_L = ET_0 K_{mc} K_s K_d \quad (1)$$

where ET_0 represents the reference evapotranspiration in a regional typical condition, and the landscape coefficient (K_L) is a product of three factors: species (K_s), density (K_d) and microclimate (K_{mc}).

The species factor (K_s) is calculated in accordance with the water demand of various plant species. Costello and Jones (2014) classified approximately 3500 species in California into four groups based on their water requirements: high (70–90% ET_0), moderate (40–60% ET_0), low (10–30% ET_0) and very low (< 10% ET_0). Since there are substantially different climate zones in California, species were evaluated for six regions which represent different climatic conditions (Costello et al., 2000). These climatic regions were in accordance with many of the world's climatic regions (Waller and Yitayew, 2015). The species factor (K_s) is based on water use studies for landscape species regardless of vegetation type (e.g. tree, shrub, herbaceous and mixed plantings) (Costello et al., 2000). Multiple-species plantings that have similar water requirements get assigned the same K_s values. In cases where species with different water requirements are planted in the same irrigation zone, it is recommended to use alternative approaches to estimate K_s, as discussed by Costello et al. (2000).

The density factor (K_d) used in the landscape coefficient formula is assigned to bring to account differences in vegetation density in a landscape, which leads to different rates of water loss through ET (Costello et al., 2000; Wolf and Lundholm, 2008). Since it is very difficult to account canopy cover and vegetation tiers for all the variation in landscape vegetation density, Costello et al. (2000) proposed a specific factor to simplify density assessments. A density factor is assigned between 0.5 and 1.3 and is divided into three categories of low (0.5–0.9), average (1.0) and high (1.1–1.3) based on a range of immature and sparse plantings to mixed and mature vegetation (Costello et al., 2000).

Microclimate is an expression used for areas having different environmental conditions within a particular climate zone (Nouri et al., 2013c). These conditions include the layout of the street network,

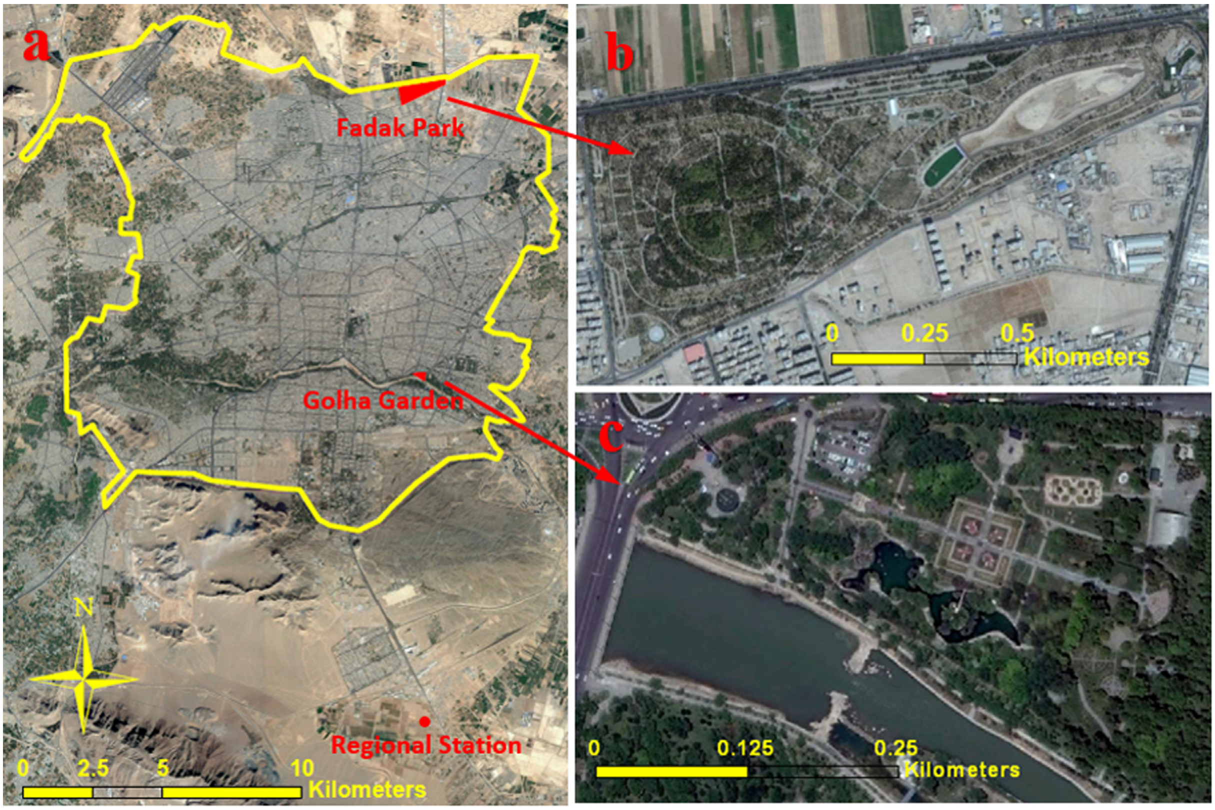

Fig. 1. (a) Aerial photograph of Isfahan city showing the location of the study sites and a regional weather station. (b) Aerial photograph of Fadak Park, (c) Aerial photograph of Golha Garden (Images Courtesy of Google Earth).

orientation and distribution of buildings (Edussuriya, 2000; Erell and Williamson, 2007), building height (Givoni, 1998; Chen et al., 2016), and the extent of vegetated permeable surfaces and non-permeable materials (Mahmood et al., 2014; Shojaei et al., 2017). These factors all influence air temperature, wind, light intensity and humidity and consequently the landscape ET (Costello et al., 2000; Shojaei et al., 2017). The microclimate factor ranges from 0.5 to 1.4, and is divided into three categories: low (0.5–0.9), average (1.0) and high (1.1–1.4). A K_{mc} of 1 is assigned for a setting close to the standardized reference condition (Costello et al., 2000).

2.2.1. WUCOLS coefficients at study sites

Table 1 shows the K_s, K_d and K_{mc} allocated for two study sites. In this study, based on WUCOLS instruction, a constant was assigned for microclimate coefficient (K_{mc}) throughout the year. Also, a constant K_s was assigned for each plant cover throughout the year, but since the area of each plant cover type changed during the year, the K_s values for each month were calculated by weighted averaging of K_s of each cover in that month, therefore, as shown in Table 1, the K_s values were different for each month. The density coefficient (K_d) changed over time due to the changes in extent of coverage from deciduous plants.

A microclimate coefficient of 1 was selected for Golha Garden as it is a well-vegetated park and is not exposed to atypical winds (Costello et al., 2000). A microclimate coefficient of 1.1 was assigned for Fadak Park considering the influence of urban features including parking lots, streets, pavements and bare soil surfaces which increase the microclimate coefficient (Costello et al., 2000).

In order to assign values for the K_s in this study, regions 2 and 4 of California (those most similar to climate condition in Isfahan), were selected. The K_s values for both parks were estimated based on recommended values of plant water needs provided by WUCOLS literature and advice from local horticulturists. A K_s value of 0.5 was assigned for Golha Garden, according to moderate water requirements of the majority of landscape species. Also, for 3 types of Golha turf grasses (Festuca sp, Kentucky bluegrass and Lolium perenne), a K_s value of 0.7 was allocated. For Fadak Park, a K_s value of 0.3 was allocated for trees and shrubs corresponding to low water requirement and a K_s value of 0.7 for turf grasses as they were similar to those at Golha Garden. The various planting types were identified through on-site inspection. The percentage of various surface covers within the study sites were measured using aerial photographs from Google Earth for each month. Finally, the values of K_s and K_d for the study sites were calculated for each month using an average value weighted by the measured plant covers for each monthly period (Table 1). The K_L value ranged from

Table 1
Coefficients of WUCOLS method.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Golha	K_s	0.63	0.63	0.62	0.61	0.6	0.6	0.6	0.6	0.6	0.61	0.62	0.63
	K_d	0.5	0.5	0.7	0.9	1.15	1.15	1.15	1.15	1.15	1	0.7	0.6
	K_{mc}	1	1	1	1	1	1	1	1	1	1	1	1
Fadak	K_s	0.38	0.38	0.37	0.36	0.36	0.36	0.36	0.36	0.36	0.37	0.38	0.38
	K_d	0.6	0.6	0.65	0.7	0.8	0.8	0.8	0.8	0.8	0.75	0.7	0.65
	K_{mc}	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

0.32 to 0.69 for Golha Garden and from 0.25 to 0.32 for Fadak Park. The K_L of Fadak is in accordance with the value of 0.3 which was proposed by Smeal et al. (2010) for water management planning on xeric landscapes (Smeal et al., 2010).

2.3. Landscape irrigation management program method

A more quantitative method to estimate landscape evapotranspiration that was initially proposed by Snyder and Eching (2005) is the Landscape Irrigation Management Program (LIMP). The landscape evapotranspiration calculated by LIMP is determined using Eq. (2) (Snyder et al., 2015):

$$ET_l = ET_0 K_{mc} K_v K_d K_{sm} = ET_{0l} K_v K_d K_{sm} \tag{2}$$

where K_{mc}, K_v, K_d, and K_{sm} represent the microclimate, vegetation, plant density, and managed water stress coefficients, respectively and ET_{0l} represents the reference evapotranspiration in a local microclimate. Either estimated or measured local microclimate data are used to determine ET_{0l} using the same standardized reference ET equations used for the regional ET_0 (Snyder et al., 2015). It should be noted that the local microclimate data should be measured in situ over a well-watered grass surface (Snyder et al., 2015).

The K_v vegetation factor is the ratio of ET_v (evapotranspiration of well-watered vegetation with ground shading over 70%) to ET_{0l} (Allen et al., 2011; Romero and Dukes, 2010). The only categorized estimation for K_v is proposed by Allen et al. (2011) who assigned a range of 0.7–1.2 for general species types under high density and full water supply. The value of K_v can be larger than 1 when landscape plants are taller and rougher than standard 0.12 m reference grass (Allen et al., 2011). It is assumed that plant physiology changes are not significant during the year, so one value is used for K_v all year around (Snyder and Eching, 2005).

The K_d density coefficient is estimated using the following equation:

$$K_d = \sin\left(\frac{\pi C_G}{140}\right) \tag{3}$$

where C_G is the percentage of ground shaded by green vegetation, when this value is less than 70%. It is assumed that most of solar radiation is intercepted by vegetation when the midday shading exceeds 70% and there is no additional energy for evaporation for canopies which have more than 70% shading, therefore K_d is assigned a value of 1 where green canopies provide more than 70% cover (Snyder and Eching, 2005; Snyder et al., 2015; Snyder, 2010).

The K_{sm} is an intentional and managed stress factor that can be estimated based on the experience and observation of local horticulturists (Allen et al., 2011). The managed water stress for general landscape plant types was categorized by Allen et al. (2011) to three levels of high, average and low stress. K_{sm} values were proposed to be 0.4, 0.6 and 0.8 for the mixture of trees, shrubs and ground covers under high, average and low stress, respectively, and 0.7, 0.8 and 0.9 for the cool season turf grass under high, average and low stress, respectively.

2.3.1. LIMP coefficients at study sites

Table 2 shows K_v, K_d and K_{sm} values assigned for each month for the two study sites. As stated in Section 2.2.1, since the area of each plant cover changed during the year, the coefficients values for each month were calculated using an average value weighted by each measured surface cover in that month, therefore, as shown in Table 2, the coefficients values were different for each month.

Since ET_v (Section 2.3) has not been measured, we could not estimate K_v in situ, therefore we used K_v proposed by Allen et al. (2011). A K_v value of 1.2 was assigned to the mixture of trees, shrubs and ground cover in Golha Garden, while a value of 1.15 was allocated for trees in Fadak Park. A K_v value of 0.9 was used for turf grass at both sites. In this study, values of K_{sm} were assumed based on values proposed by Allen et al. (2011). For Golha Garden, an average level of stress management has been applied to sustain a good aesthetic appearance since it has a large diversity of plant species. Therefore, a K_{sm} of 0.6 was assigned to the mixture of trees, shrubs and ground covers and a K_{sm} of 0.8 for the cool season turf grass of Golha.

As stated in Section 1, the Municipality of Isfahan has a strong focus on sustainable management of limited water resources. It can be achieved through water stress management of the plants (Nouri et al., 2013d). To approach this goal, we considered whether there was a possibility to apply a high water stress for Fadak Park as the majority of vegetation in Fadak are resistant to drought. Therefore, we applied two managed water stress levels of average and high for Fadak Park. K_{sm} values of 0.6 under average stress and 0.4 under high stress were applied. For cool season turf grass, K_{sm} values of 0.8 under average stress and 0.7 under high stress were applied according values proposed by Allen et al. (2011). The percentage of various surface covers within the study sites were measured using aerial photographs from Google Earth for each month. The value of each coefficient for the study sites was calculated for each month using an average value weighted by the measured surface covers (Table 2).

2.4. LIMP versus WUCOLS

Both the WUCOLS and LIMP methods provide factor-based estimations of urban landscape water requirement, however there are some differences in the coefficients and their ranges. For example, K_d in the LIMP method is calculated more accurately compared to the WUCOLS method, and the K_s in WUCOLS method includes the effects of both plant species and water stress which are treated separately by the LIMP approach (Allen et al., 2011; Snyder, 2010).

2.5. Statistical analysis between WUCOLS and LIMP

To perceive the significant differences between the daily ET_l estimated by two methods, the Independent Sample T-test was used. This test was performed for each month during 3 years of study using SPSS (IBM Corp. released 2010, Version 19). The null-hypothesis tested was "no significant difference between the daily ET_l estimated by the WUCOLS and LIMP methods". A confidence level of 95% was chosen.

2.6. Reference evapotranspiration

In this study, one of the Valiantzas expressions (Eq. (4)) was employed to estimate reference evapotranspiration (Valiantzas, 2013) because only temperature and humidity data were available for the study sites:

$$ET_0 \approx 0.0393 R_s \sqrt{|T + 9.5|} - 0.19 R_s^{0.6} \varphi^{0.15} + 0.078(T + 20)\left(1 - \frac{RH}{100}\right) \tag{4}$$

where R_s is solar radiation (MJ/m^2/d), T is the average air temperature, φ is the latitude (rad), and RH is the relative humidity (%).

We selected Eq. (4) to estimate ET_0 in this study based on the findings of Valiantzas (2013). Their study demonstrated that Eq. (4) estimates ET_0 more accurately compared to other empirical equations which are used where limited meteorological data is available, including the Hargreaves method, the Turk method and the reduced set FAO-56 Penman-Monteith schemes (Valiantzas, 2013). Valipour (2015) compared the reference evapotranspiration values of Isfahan using two methods: Eq. (4), and the FAO Penman-Monteith method, and found Eq. (4) an accurate method for Isfahan. A 30-year dataset from 12 synoptic stations in Isfahan province, was used. The coefficient of determination (R^2), the standard error of the estimate (SEE) and the systematic error (S) were calculated to be 0.9947, 0.472 mm/d and 1.025, respectively (Valipour, 2015). Further evidence in favour of Eq. (4) was provided by Yazdanpanah (2017) compared the reference evapotranspiration values of Isfahan using two methods of Valiantzas (Eq.

Table 2
Coefficients of LIMP method.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Golha	K_v	1.01	1.01	1.02	1.03	1.03	1.04	1.04	1.04	1.04	1.03	1.02	1.01
	K_d	0.3	0.3	0.5	0.9	1	1	1	1	1	0.9	0.6	0.3
	K_{sm}	0.73	0.73	0.72	0.71	0.7	0.7	0.7	0.7	0.7	0.71	0.72	0.72
Fadak	K_v	1.11	1.11	1.12	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.11	1.11
	K_d	0.62	0.62	0.63	0.65	0.71	0.71	0.71	0.71	0.71	0.7	0.68	0.62
	K_{sm} [a]	0.62	0.62	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.62	0.62
	K_{sm} [b]	0.42	0.42	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.42

[a] Under average managed water stress.
[b] Under high managed water stress.

(4)), and the FAO Penman-Monteith for a period of 3 years. The results showed an average R^2 of 0.86.

2.7. Irrigation water requirement

The water requirement of an irrigated plant for evapotranspiration is determined using the following equation (Allen et al., 2011; Gheysari et al., 2015).

$$IR_n = ET_l - P_e - \text{GW} - \Delta\theta z_s \tag{5}$$

where IR_n is the net irrigation requirements, P_e is the effective precipitation which is the part of precipitation that infiltrates into the soil and is retained in the root zone and is used to offset transpiration of the plant, $\Delta\theta$ is the average change in soil water content in the root zone during the period of calculation, GW is the contributions of shallow groundwater, z_s is the depth of soil experiencing the change in water content.

For the periods shorter than one irrigation season, $\Delta\theta$ over time is assumed to be zero (Allen et al., 2011).

The gross irrigation water requirement (IR_g), is different with the water volume beneficially used by the plant (including leaching) (Waller and Yitayew, 2015). The gross irrigation water requirement is estimated by the following equation to compensate for water losses (Kiani et al., 2016):

$$IR_g = \frac{IR_n}{E_a} \tag{6}$$

where E_a is irrigation efficiency. Based on the expert opinion of horticulturalists working in Golha Garden, an irrigation efficiency of 75% was assumed for the showerhead hose irrigation. Based on advice from the manager of Fadak Park, an irrigation efficiency of 80% was assumed for Fadak Park which include both showerhead hose irrigation and drip irrigation. It should be noted that the efficiency of drip irrigation was stated 90% in Annex 1 of FAO.

2.8. Meteorological data

The meteorological dataset was obtained from the Research Centre for Atmospheric Chemistry, Ozone and Air Pollution in Isfahan province (http://www.esfahanmet.ir/) for the years of 2011, 2012 and 2013 to estimate regional reference evapotranspiration. In addition, air temperature and relative humidity were measured using identical Data loggers (Model 8808, AZ Co.) at two stations in Golha Garden and Fadak Park at 5 min intervals (Figs. S1–S4). Each was situated 1.8 m above the ground level. The temperature range of Data Logger was −20 to 70 °C, with a resolution of 0.1 °C and an accuracy of ± 0.6 °C over the range 0 to 50 °C, and ± 1.2 °C outside this range. The humidity range was 0% to 100%, with a resolution of 0.1% and an accuracy of ± 3% over the humidity range 10–90% and temperature of 25 °C, and ± 5% outside this range. Hourly temperature/humidity were calculated by averaging 5-minute data over each hour. Daily mean temperature/humidity were calculated by averaging the daily minimum temperature/humidity and daily maximum temperature/humidity. Data loggers were calibrated every six months under identical controlled conditions.

We used the precipitation data from weather stations near the study sites which were managed by the Iran Meteorological Organization (http://www.irimo.ir). The Thiessen method (Thiessen, 1911) was employed to estimate the precipitation rate at each site. We estimated the effective rainfall by a simplified version of the USDA SCS method which was used in CROPWAT v8.0 model (Smith, 1992). This method is appropriate for semi-arid environments which have high potential evapotranspiration (Hess, 2010).

In order to estimate local reference evapotranspiration, ET_{0l}, using Eq. (4), we applied the solar radiation values, R_s, recorded in the regional station (Fig. 1) as we could not measure on-site R_s (in situ) at each study site. To reduce the probability of error, we removed data of cloudy days and analysed sunny days only throughout the monitoring period.

2.9. Irrigation data

The plant water requirement for both study sites were sourced from the groundwater resources (in-situ wells). We estimated the seasonal applied water volume at study sites according to irrigation schedule executed by the parks organization, and on-site measurement. The seasonal applied water volume data (m^3) were transformed to depth (mm), taking into account the landscape area in each site. Table 3 presents the seasonal and annual applied irrigation water at study sites.

3. Results

3.1. Landscape evapotranspiration

Monthly ET_l values estimated by the LIMP (under average managed stress) and WUCOLS methods are shown in Fig. 2. Monthly ET_l values for Golha Garden ranged from 18 to 153 mm (WUCOLS) and 10 to 168 mm (LIMP) while monthly $ET_{l.WUCOLS}$ and $ET_{l.LIMP}$ at Fadak Park ranged from 13 to 65 mm and 17 to 121 mm, respectively (Fig. 2).

Fig. 3 presents the ratio of daily $ET_{l.LIMP}$ to $ET_{l.WUCOLS}$ at each site and in each year of the study. This ratio ranged from 0.40 to 1.4 for Golha Garden and from 1 to 2.3 for Fadak Park. A clear pattern can be observed in all three years of study. The differences in landscape plant water demand estimated by the WUCOLS and LIMP methods were not consistent throughout the year, however there is a consistent pattern in all three years (Fig. 3).

Table 4 presents the results of statistical comparison of daily ET_l

Table 3
Seasonal and annual applied water (mm) at each study site.

	Winter	Spring	Summer	Autumn	Annual
Golha Garden	30	400	666	270	1366
Fadak Park	51	198	372	153	774

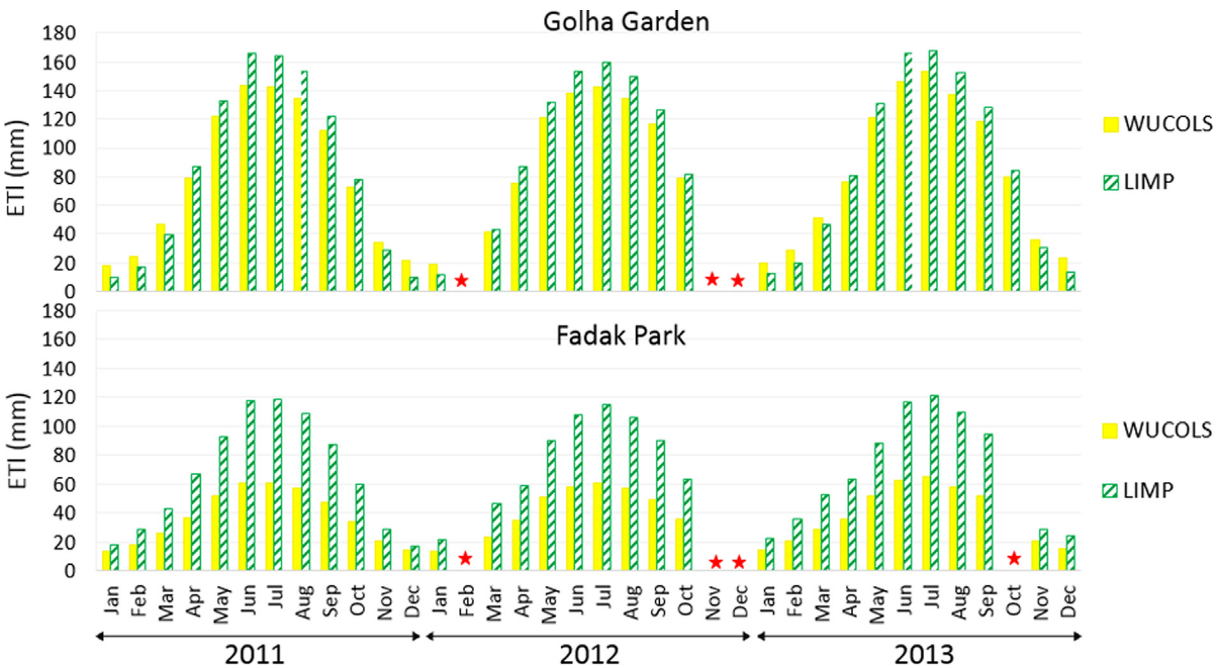

Fig. 2. Monthly average landscape evapotranspiration (ET_l) by the LIMP and WUCOLS methods at study sites over the years of 2011, 2012 and 2013. LIMP was applied under average managed stress. Asterisks show months with missing data.

estimated by the WUCOLS and LIMP methods. Generally, differences are statistically significant.

The total annual water requirement estimated by WUCOLS at Golha Garden was 964 mm, 5% lower than the LIMP estimate of 1016 mm, as shown in Table 5. The total annual water requirement estimated by WUCOLS at Fadak Park was 445 mm, 44% lower than the LIMP estimate of 794 mm (Table 5).

3.2. Gross irrigation requirement

Fig. 4 present the monthly estimations of gross water requirement by the LIMP and WUCOLS methods at study sites. The LIMP method was applied under two managed water stress levels of average (LIMP-AS) and high (LIMP-HS) at Fadak Park as stated in Section 2.3.1, while an average water stress was used for Golha Garden. The gross water requirement was obtained by applying the irrigation efficiency to the net water requirement. To estimate net water requirement, the monthly effective precipitation was subtracted from the landscape evapotranspiration rate as stated in Section 2.7.

A seasonal trend is evident in Fig. 4 that is related to vegetation physiology performance during different seasons. Peak values were found from Jun to Aug indicating maximum gross irrigation requirements in summer. In general, the minimum irrigation demand was observed from November to March (mid-autumn to early spring) due to the low evapotranspiration of vegetation during winter dormancy and high precipitation. The values of monthly gross water demand in different years had the most variability from October to May due to significant changes in the effective rainfall rate during autumn-spring in three years of this study.

A gross water demand of zero shows that the effective precipitation exceeded evapotranspiration and therefore irrigation should have been stopped. This happened in November 2011 for both study sites, and in April 2012 and November 2013 at Fadak Park when evapotranspiration was estimated by the WUCOLS and LIMP-HS methods (Fig. 4). In these periods, there was a high contribution of effective rainfall in providing required irrigation water.

As shown in Table 6, at both sites, the seasonal gross irrigation demand reached a maximum in summer when it was estimated by the LIMP method. The LIMP-AS estimations for the summer gross irrigation needs at Golha and Fadak, were approximately 49% and 46% of the

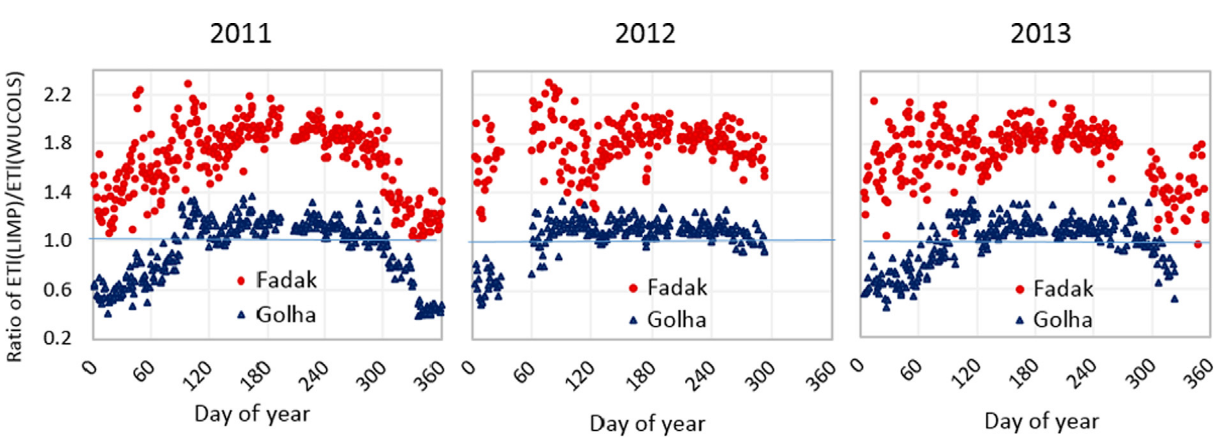

Fig. 3. Ratio of daily evapotranspiration (ET_l) computed by LIMP (under average water stress) and WUCOLS at study sites for the years of 2011, 2012 and 2013. Discontinuity in graphs is due to missing data.

Table 4
Results from statistical analysis[a] between the daily evapotranspiration (ET_l) estimated by LIMP (average water stress) and WUCOLS methods over 2011, 2012 and 2013.

		Golha			Fadak		
		2011	2012	2013	2011	2012	2013
$ET_{l(WUCOLS-LIMP)}$	January	0.26*	0.22*	0.24*	−0.14*	−0.27ns	−0.27* ns
	February	0.24*	–	0.28*	−0.40*	–	−0.51*
	March	0.26*	−0.02ns	0.18ns	−0.52*	−0.62*	−0.60*
	April	−0.54*	−0.40*	−0.51*	−0.95*	−0.81*	−0.88*
	May	−0.34ns	−0.35ns	−0.32ns	−1.32*	−1.24*	−1.21*
	June	−0.77*	−0.52*	−0.65*	−1.89*	−1.64*	−1.84*
	July	−0.71*	−0.59*	−0.48*	−1.93*	−1.83*	−1.83*
	August	−0.60*	−0.49*	−0.51*	−1.81*	−1.63*	−1.78*
	September	−0.30*	−0.33*	−0.31*	−1.32*	−1.34*	−1.35*
	October	−0.17ns	−0.11ns	−0.05ns	−0.84*	−0.86*	–
	November	0.21*	–	0.21*	−0.35*	–	−0.37*
	December	0.39*	–	0.33*	−0.11ns	–	−0.28*

[a] Comparison of means was done with Independent Sample T-test. Significant ET_l differences on the 5% level are indicated with an asterisk (*).

Table 5
Average of the seasonal and annual water need (mm) estimated by LIMP (average water stress) and WUCOLS methods at study sites over 2011, 2012 and 2013.

Site	Method	Winter	Spring	Summer	Autumn	Annual
Golha	WUCOLS	83	309	406	166	964
	LIMP	63	339	454	160	1016
Fadak	WUCOLS	55	136	173	82	445
	LIMP	91	245	325	134	794

total gross irrigation need throughout the year, respectively (Table 6). These values changed to about 47% and 45% according to the WUCOLS estimation. On average, the annual estimation of gross irrigation need by WUCOLS at Golha Garden and Fadak Park were respectively, 6% and 47% lower than LIMP-AS estimates (Table 6).

4. Discussion

4.1. Landscape evapotranspiration

As shown in Fig. 2, Golha Garden had a higher ET_l from April to October (early spring to mid-autumn in Iran) compared to Fadak Park. This is because Golha Garden had denser plant coverage with a higher water demand category. Monthly $ET_{l.LIMP}$ values at Golha Garden were higher than $ET_{l.WUCOLS}$ values except from November to March. However, at Fadak Park, $ET_{l.LIMP}$ was higher than $ET_{l.WUCOLS}$ throughout the year. During temperate and warm months (March to October), there were more considerable differences between $ET_{l.WUCOLS}$ and $ET_{l.LIMP}$ values at Fadak Park than those at Golha Garden (Fig. 2). In fact, differences in the monthly estimates of landscape water demand by the WUCOLS and LIMP methods were not similar at the two sites. Based on the results of Golha Garden, it seems that the LIMP (average water stress) and WUCOLS methods estimate similar values of ET_l in the presence of a great diversity of plant species, mostly deciduous, and

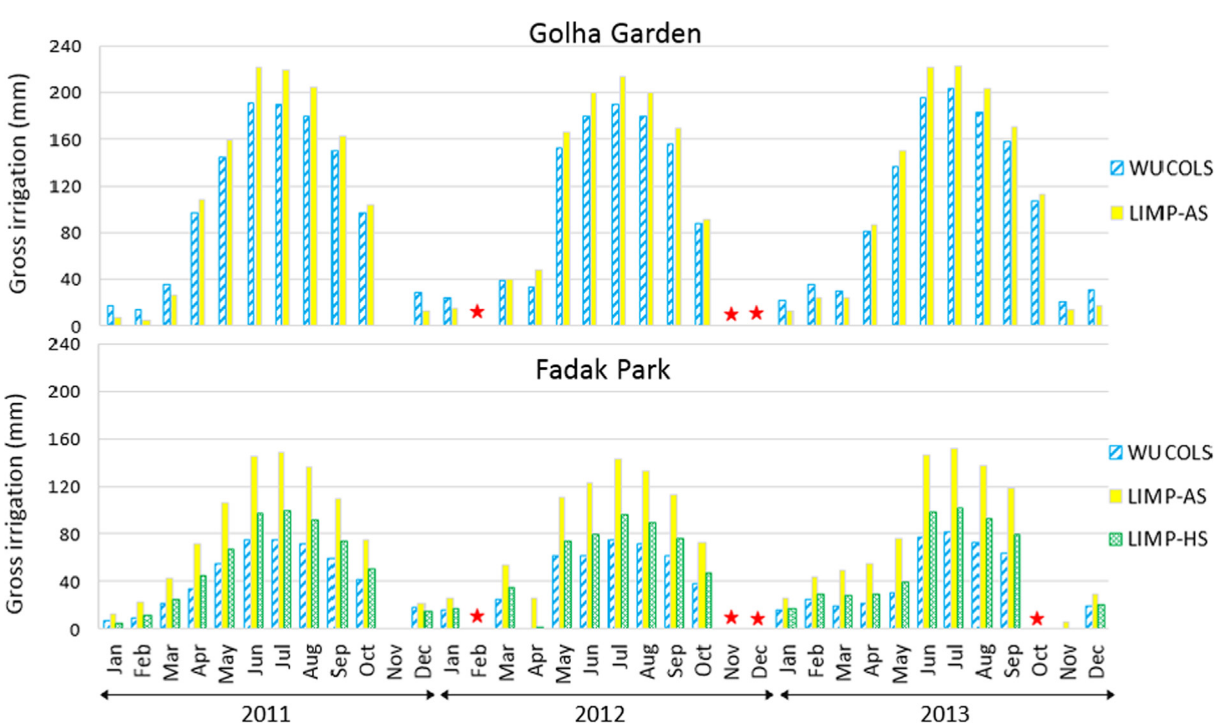

Fig. 4. Monthly gross irrigation requirement at study sites estimated by WUCOLS and LIMP methods in 2011–2013. Asterisks show months with missing data.

Table 6
Seasonal and annual estimations of gross irrigation need (mm) by LIMP and WUCOLS methods in 2011, 2012 and 2013 at study sites.

Site	Method	Year	Winter	Spring	Summer	Autumn	Annual
Golha	WUCOLS	2011	65	382	533	166	1146
		2012	–[a]	318	533	–[b]	–
		2013	89	358	557	180	1183
	LIMP-AS	2011	34	424	606	167	1232
		2012	–[a]	362	596	–[b]	–
		2013	60	392	614	181	1246
Fadak	WUCOLS	2011	36	145	211	73	466
		2012	–[a]	107	208	–[b]	–
		2013	59	109	223	–[d]	–
	LIMP-AS	2011	70	289	406	125	889
		2012	–[a]	236	392	–[b]	–
		2013	112	245	416	–[d]	–
	LIMP-HS	2011	38	185	273	84	579
		2012	–[a]	140	262	–[b]	–
		2013	71	144	280	–[d]	–

[a] There was no data available for February.
[b] There was no data available for November and December.
[d] There was no data available for October.

more similar to the reference station condition in terms of wide turf cover. In contrast, the difference in estimates of ET_l by two methods were greater at Fadak Park, a landscape with less diversity, a majority of evergreen, drought-tolerate species and a lower percentage of turf cover. It should be noted that in this study, we used the values of K_v proposed by Allen et al. (2011) for the LIMP method and this coefficient was not measured in situ based on the LIMP instruction (Section 2.3). Therefore, LIMP estimations in this study may have less accuracy compared to LIMP estimations if K_v was measured in situ.

As shown in Fig. 3, the ratio of $ET_{l.LIMP}$ to $ET_{l.WUCOLS}$ at Fadak Park has scattered during dormancy and initial growth period (about JD 300 to 360 and 0 to 120). The reason for scattering of this ratio can be related to the increase of variation of daily ET_{0l} (Eq. (2)) from November to April when is mid-autumn to mid-spring in Iran. In fact, daily ET_{0l} values in the LIMP method (Eq. (2)) are more scattered during this period, more likely due to the effects of precipitation and higher wind speed on change of local microclimate conditions during winter and spring. In Isfahan city, most rainfall frequency occurs from mid-autumn to mid-spring, also, wind speed reaches the highest value in early spring (based on 30 years of rainfall and wind records by Iran Meteorological Organization). Despite the increase of variation of daily ET_{0l} during winter and spring at Golha Garden, the scattering of the ratio of daily $ET_{l.LIMP}$ to $ET_{l.WUCOLS}$ was not evident in Fig. 4, because the product of values multiplied by Golha Garden ET_{0l} (i.e. $\frac{K_v K_d K_{sm}}{ET_0 K_{mc} K_s K_d}$) were too low during winter and spring which reduced the changes of ratio of daily $ET_{l.LIMP}$ to $ET_{l.WUCOLS}$ at Golha Garden.

4.2. Comparison of applied water and gross irrigation need

In general, the applied water at Golha Garden was higher than the estimations of ET_l by the WUCOLS and LIMP (average water stress) in all seasons except winter (Fig. 5). Also, the applied water at Fadak Park was lower than the LIMP estimations (average water stress) in all seasons except autumn and higher than the estimations of ET_l by LIMP (high water stress) and WUCOLS in all seasons except winter (Fig. 6).

4.2.1. Golha Garden

Comparing the seasonal gross irrigation need with the applied water volume for Golha Garden showed that extra irrigation occurred in all seasons except winter (Fig. 5). On average, WUCOLS estimated an average annual irrigation need of 1164 mm which is 15% less than the applied value of 1366 mm while the LIMP estimate of 1239 mm was 9% less than the applied value.

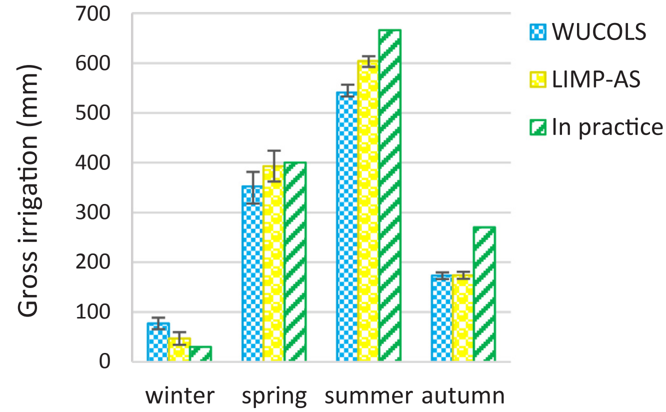

Fig. 5. Average rate of seasonal gross irrigation need estimated by the WUCOLS and LIMP (average water stress) methods at Golha Garden compared to applied irrigation in 2011–2013. Error bars indicates the maximum and minimum value during the study period.

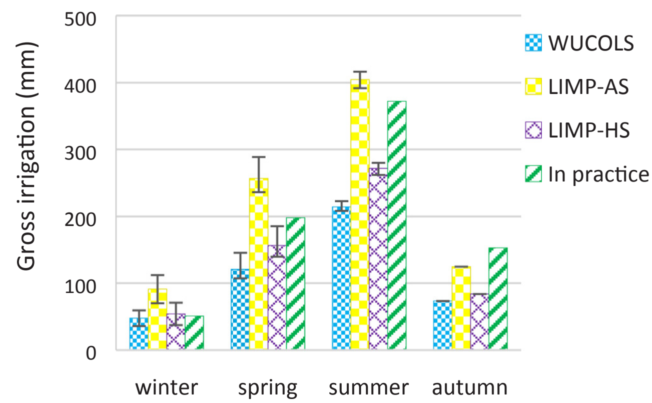

Fig. 6. Average of seasonal gross irrigation need estimated by the WUCOLS and LIMP methods at Fadak Park and water applied in practice. The LIMP estimations shown include two assumed managed water stress levels-average (LIMP-AS) and high (LIMP-HS). Error bars indicate the maximum and minimum amounts over the years of 2011, 2012 and 2013.

Taking into account the water resource limitations in Isfahan city and estimated irrigation requirements in Fig. 5, decision makers could reduce the amount of irrigation in summer and autumn at Golha Garden, however, based on the local horticulturists opinion, the applied water values created an acceptable aesthetic level in this garden. We believe that reduction of irrigation amount to the LIMP-AS estimations more likely may not have a negative impact on the greenness, health and appearance of this urban park because a wide range of ornamental plants can perform well in the landscape on reduced levels of irrigation (Kjelgren et al., 2000; Reid and Oki, 2016). It should be noted that the LIMP method was applied under an average managed water stress for Golha Garden (Section 2.3.1). This means that over-reduction in irrigation rate to levels below LIMP estimations may cause damage to plants as this garden contains over 200 plant species of which majority are not tolerant to the high level of water stress.

4.2.2. Fadak Park

Fig. 6 presents the seasonal average of the gross water need over three years of study at Fadak Park. The applied water was lower than the LIMP estimates under an average managed stress (LIMP-AS in Fig. 6) in all seasons except autumn for all three years of study. The applied water met the irrigation need estimated by LIMP under a high water stress (LIMP-HS in Fig. 6) for all seasons except winter 2013. The increase of water stress at Fadak Park could lead to a reduction of about 27% in annual irrigation demand. The WUCOLS estimations were lower than the applied water at Fadak Park for all seasons during the study period (except winter 2013) up to 44% in summer 2012 (Fig. 6). The WUCOLS estimations were closer to LIMP estimations under a high water stress. On average, WUCOLS estimated an annual irrigation need of 456 mm which is 41% lower than the actual application (774 mm) and LIMP-HS determined a value of 566 mm, 27% lower than the applied water.

Based on field inspections and local horticulturists opinion, the applied water in Fadak Park created approximately an acceptable aesthetic level. Since the applied water was closer to the LIMP-AS estimations in summer which is the season with the highest irrigation need, we found that the LIMP method under average managed water stress can provide a suitable estimation for water demand in Fadak Park (Fig. 6). The reduction of irrigation amount to LIMP-HS could present water savings, but may also cause some level of damage to vegetation in this park. We therefore recommend performing a pilot scheme in this park to investigate whether watering based on the LIMP-HS causes any significant damage as this irrigation strategy can lead to an annual water saving of 27%. Notably, Hilaire et al. (2008) stated that some landscapes in arid urban regions can maintain acceptable aesthetic appearance with less water than is indicated from a calculated water budget.

4.3. Management considerations and recommendations

As shown in Figs. 5 and 6, the applied water volumes in autumn were higher than the gross water needs estimated by both methods of WUCOLS and LIMP at both sites. These outcomes showed that irrigation managers were not considering rainfall (green water) in their irrigation scheduling because during the study period, most rainfall events occurred during autumn that could be considered as a valuable source of water to irrigate the urban greeneries, but during this time, irrigation management was only based on the groundwater which is a type of blue water resources (Civit et al., 2018; Owusu-sekyere et al., 2017). This mismanagement of green and blue water resources, which is an emerging topic in water management studies particularly in agriculture, is not limited to agricultural farms but also urban green spaces. Smart management of green and blue water resources needs to deliberated quickly and thoroughly, particularly in areas experiencing water shortage (Nouri et al., 2018).

Our results showed that the volume of irrigation applied during winter was lower than that estimated by both WUCOLS and LIMP at both sites during the study period (Figs. 5 and 6). This also might have occurred due to that irrigation decision makers have not accounted for rainfall events in irrigation calculations because there is an inherent assumption in irrigation planning that the majority of rainfall occurs during winter in Isfahan. While this is true based on 30 years of precipitation records from the Iran Meteorological Organization, during the three years of this study, the most rainfall actually fell in autumn.

We therefore recommend that a strategy to improve irrigation management of urban parks in Isfahan and other arid urban environments is to revise fixed irrigation rate to take into account climatic conditions, particularly, rainfall rates. The need to adjust the irrigation rate was more noticeable in spring when the gross water need of Golha Garden and Fadak Park had significant differences of 64 mm (by WUCOLS) and 53 mm (by LIMP-AS), respectively during the study period (Table 6). With consideration of the current water crisis conditions in Isfahan and the results of this study, we recommend existing weather monitoring data be used to actively consider effective rainfall and continuously revise vegetation irrigation requirements. Soil water monitoring to adequately determine the irrigation timing and volume based on depleted water within the root zone (Gheysari et al., 2017, Kiani et al., 2016) could be another approach to improve irrigation management in urban turf grass landscapes. However, this method has previously been noted to be not a practical approach for heterogeneous urban landscapes (Nouri et al., 2016).

Since local horticulturists confirmed an acceptable level of vegetation health and greenness at both sites, we found that the WUCOLS method may have underestimated water needs of both sites during warm seasons. This finding is consistent with Nouri et al. (2016) who demonstrated that the annual WUCOLS estimation was 26% lower than the Soil Water Balance (SWB) method and 26.3% lower than the Enhanced Vegetation Index (EVI) method using data from MODIS (Moderate Resolution Imaging Spectroradiometer) within the Adelaide Parklands, Australia.

In study sites, the LIMP method (assuming average managed water stress) provided closer estimations to the applied water volume, however we used values of K_v proposed by Allen et al. (2011) for the LIMP method which means this coefficient was not measured locally; this assumption may have introduced error and bias to the outcomes. Therefore, It is recommended that further research be undertaken into measurement of K_v locally based on LIMP instruction (Section 2.3). We suggest that the LIMP method provides more accurate estimations due to taking to account different levels of water stress in irrigation management while the WUCOLS method neglected it.

As stated in Section 2.2, the species coefficient (K_s) in WUCOLS method is based on water use studies for landscape species. This means that WUCOLS combines species factor and managed water stress into K_s (Allen et al., 2011). The combination of these two factors may lead to error in estimating the species coefficient for plants outside California because the WUCOLS method has recommended the species coefficient values for plants in that area specifically. The results showed that the WUCOLS method might have significant under-estimates in some landscapes – for example, the predicted water demand of Fadak Park was up to 47% less than applied water during summer 2012, where site inspection showed good health and greenness.

We also recommend performing a pilot scheme in Fadak Park to investigate whether assuming a high water stress for LIMP method causes some level of damage to vegetation as this irrigation strategy can lead to an annual water saving of 27%. The results of this trial would be of benefit to irrigation managers in all arid urban environments to improve urban irrigation practices and reduce the demand for limited urban water resources.

More broadly, we also recommend to use some alternative sources such as treated wastewater (grey water) for landscape irrigation in arid areas (Zhang et al., 2010). However, it needs adequate treatment and reticulation infrastructure also management considerations including irrigation timing (to reduce human contact), soil salinization, plant damage and nutrient leaching (Hilaire et al., 2008; Nouri et al., 2013a,b; Paulo et al., 2013). Also, in response to the current water crisis, we suggest using drought-tolerant and native plants, although selection of landscape plant species is affected by plant availability, functionality, cost, and its aesthetic value (Spinti et al., 2004).

5. Conclusion

In the dry region of Isfahan in central Iran, an accurate estimation of urban landscape water need is critically important. In this study, the vegetation water needs for two urban green spaces (Golha Garden and Fadak Park) were estimated using two factor-based approaches, WUCOLS and LIMP.

On average, the annual water requirement at Golha Garden and Fadak Park estimated by the WUCOLS method was 5% and 44% lower, respectively, than LIMP estimations. Based on the actual irrigation volume and plant health and aesthetic appearance at each site, the WUCOLS method was considered to potentially underestimate plant water requirements in warm seasons. The outcomes of this research showed that the LIMP method can lead to a water saving of 9% in a garden with a great diversity of plant species, mostly deciduous, and with broad turf cover. We found the LIMP method to be more reliable because of its feasibility in including water stress in irrigation management, which was not explicitly considered by the WUCOLS method.

Our results showed that the irrigation applied during winter was low, while excess irrigation was applied during autumn at both sites during study period. This may be attributed to irrigation managers not modifying the irrigation requirements based on effective rainfall throughout the year, rather relying on long-term average climate data.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecoleng.2018.08.021.

References

Allen, R.G., Howell, T.A., Snyder, R.L., 2011. In: Irrigation Water Requirements, Irrigation, sixth ed. Irrigation Association, Falls Church, VA, pp. 93–172.
Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: Guidelines for computing crop requirements. Irrig. Drain. Pap. No. 56, FAO 300. https://doi.org/10.1016/j.eja.2010.12.001.
Amiri, R., Weng, Q., Alimohammadi, A., Alavipanah, S.K., 2009. Spatial-temporal dynamics of land surface temperature in relation to fractional vegetation cover and land use/cover in the Tabriz urban area, Iran. Remote Sens. Environ. 113, 2606–2617.
Chen, L., Yu, B., Yang, F., Mayer, H., 2016. Intra-urban differences of mean radiant temperature in different urban settings in Shanghai and implications for heat stress under heat waves: a GIS-based approach. Energy Build. 130, 829–842.
Civit, B., Piastrellini, R., Curadelli, S., Pablo, A., 2018. The water consumed in the production of grapes for vinification (*Vitis vinifera*). mapping the blue and green water footprint. Ecol. Indic. 85, 236–243.
Costello, L.R., Jones, K.S., 2014. WUCOLS IV. Water Use Classification of Landscape Species. University of California, Cooperative Extension.
Costello, L.R., Matheny, N.P., Clark, J.R., Jones, K.S., 2000. A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California. The Landscape Coefficient Method and WUCOLS III. University of California Cooperative Extension. California Department of Water Resource.
Cubino, J.P., Kirkpatrick, J.B., Subirós, J.V., 2017. Do water requirements of Mediterranean gardens relate to socio-economic and demographic factors? Urban Water J. 14, 401–408.
Dinpashoh, Y., Jhajharia, D., Fakheri-Fard, A., Singh, V.P., Kahya, E., 2011. Trends in reference crop evapotranspiration over Iran. J. Hydrol. 399, 422–433.
Edem, E., Anthony, A., Greening, U., 2014. The impact of greenery on the urban microclimate and environmental quality of Uyo metropolis, Akwa Ibom state, Nigeria 3, pp. 22–27.
Edussuriya, P.S., 2000. Impact of urban physical design attributes on urban air quality and microclimate: towards formulation of urban design guidelines for Mong Kok, HKU Theses Online, The University of Hong Kong (pokfulam, Hong Kong), Faculty of architecture, p. 97.
Erell, E., Williamson, T., 2007. Intra-urban differences in canopy layer air temperature at a mid-latitude city. Int. J. Climatol. 27, 1243–1255.
Geiger, R., 1961. Überarbeitete Neuausgabe von Geiger, R. R. Köppen-Geiger/Klima der Erde, Wandkarte 1, p. 16.
Gheysari, M., Loescher, H.W., Sadeghi, S.H., Mirlatifi, S.M., Zareian, M.J., Hoogenboom, G., 2015. Chapter three- water yield relations and water use efficiency of maize under nitrogen fertigation for semiarid environments: experiment and synthesis. Adv. Agron. 130, 175–229.
Gheysari, M., Sadeghi, S.H., Loescher, H.W., Amiri, S., Zareian, M.J., Majidi, M.M., Asgarinia, P., Payero, J.O., 2017. Comparison of deficit irrigation management strategies on root, plant growth and biomass productivity of silage maize. Agric. water Manage. 182, 126–138.
Givoni, B., 1998. Climate Considerations in Building and Urban Design. John Wiley & Sons.
Häyhä, T., Franzese, P.P., 2014. Ecosystem services assessment: a review under an ecological-economic and systems perspective. Ecol. Model. 289, 124–132.
Hess, T., 2010. Estimating green water footprints in a temperate environment. Water 2010 (2), 351–362.
Hilaire, R.S., Hall, S., Cruces, L., Arnold, M.A., Wilkerson, D.C., Devitt, D.A., Hurd, B.H., Cruces, L., Lesikar, B.J., Lohr, V.I., Martin, C.A., Mcdonald, G.V., Morris, R.L., Pittenger, D.R., Shaw, D.A., Zoldoske, D.F., 2008. Efficient water use in residential urban landscapes. HortScience 43, 2081–2092.
Hof, A., Wolf, N., 2014. Landscape and urban planning estimating potential outdoor water consumption in private urban landscapes by coupling high-resolution image analysis, irrigation water needs and evaporation estimation in Spain. Landsc. Urban Plan. 123, 61–72.
Jansson, C., 2006. Urban microclimate and surface hydrometeorological processes. TRITA-LWR PHD 1027. Doctoral Thesis in Land and Water Resources Sciences, KTH Architecture and the Built Environment, Stockholm.
Kiani, M., Gheysari, M., Mostafazadeh-Farda, B., Majidi, M.M., Karchani, K., Hoogenboom, G., 2016. Effect of the interaction of water and nitrogen on sunflower under drip irrigation in an arid region. Agric. Water Manage. 171, 162–172.
Kjelgren, R., Rupp, L., Kilgren, D., 2000. In: Water Conservation in Urban Landscapes, pp. 1037–1040.
Kottmeier, C., Biegert, C., Corsmeier, U., 2007. Effects of urban land use on surface temperature in Berlin: case study. J. Urban Plan. 133, 128–137.
Mahmood, R., Pielke, R.A., Hubbard, K.G., Niyogi, D., Dirmeyer, P.A., Mcalpine, C., Carleton, A.M., Hale, R., Gameda, S., Beltrán-Przekurat, A., Baker, B., Mcnider, R., Legates, D.R., Shepherd, M., Du, J., Blanken, P.D., Frauenfeld, O.W., Nair, U.S., Fall, S., 2014. Land cover changes and their biogeophysical effects on climate. Int. J. Climatol. 34, 929–953.
Marasco, D.E., Culligan, P.J., McGillis, W.R., 2015. Evaluation of common evapotranspiration models based on measurements from two extensive green roofs in New York City. Ecol. Eng. 84, 451–462.
Nouri, H., Beecham, S., Hassanli, A., Ingelton, G., Bolan, N., 2013a. An assessment of the drainage quality and quantity associated with recycled wastewater irrigation in an urban park. In: 13th Edition of the World Wide Workshop for Young Environmental Scientists (WWW-YES-2013)-Urban Waters: Resource or Risks? HAL-ENPC.
Nouri, H., Beecham, S., Hassanli, A.M., Ingleton, G., 2013b. Variability of drainage and solute leaching in heterogeneous urban vegetation environs. Hydrol. Earth Syst. Sci. 17, 4339–4347.
Nouri, H., Beecham, S., Hassanli, A.M., Kazemi, F., 2013c. Water requirements of urban landscape plants: a comparison of three factor-based approaches. Ecol. Eng. 57, 276–284. https://doi.org/10.1016/j.ecoleng.2013.04.025.
Nouri, H., Beecham, S., Kazemi, F., Hassanli, A.M., 2013d. A review of ET measurement techniques for estimating the water requirements of urban landscape vegetation. Urban Water J. 10, 247–259.
Nouri, H., Glenn, E.P., Beecham, S., Boroujeni, S.C., Sutton, P., Alaghmand, S., Noori, B., Nagler, P., 2016. Comparing three approaches of evapotranspiration estimation in mixed urban vegetation: field-based, remote sensing-based and observational-based methods. Remote Sens. 8. https://doi.org/10.3390/rs8060492.
Nouri, H., Chavoshi, S., Hoekstra, A., 2018. Water Footprint of Urban Green Spaces. European Geoscience Union – EGU, Vienna, Austria.
Owusu-sekyere, E., Jordaan, H., Chouchane, H., 2017. Evaluation of water footprint and economic water productivities of dairy products of South Africa. Ecol. Indic. 83, 32–40.
Ozdogan, M., Rodell, M., Beaudoing, H.K., Toll, D.L., 2010. Simulating the effects of irrigation over the United States in a land surface model based on satellite-derived agricultural data. J. Hydrometeorol. 11, 171–184.
Parés-Franzi, M., Saurí-Pujol, D., Domene, E., 2006. Evaluating the environmental performance of urban parks in Mediterranean cities: an example from the Barcelona metropolitan region. Environ. Manage. 38, 750–759.
Paulo, P.L., Azevedo, C., Begosso, L., Galbiati, A.F., Boncz, M.A., 2013. Natural systems treating greywater and blackwater on-site: integrating treatment, reuse and landscaping. Ecol. Eng. 50, 95–100.
Pearlmutter, D., Berliner, P., Shaviv, E., 2007. Urban climatology in arid regions: current research in the Negev desert. Int. J. Climatol. 27, 1875–1886.
Petralli, M., Brandani, G., Napoli, M., Messeri, A., Massetti, L., 2015. Thermal comfort and green areas in Florence. Ital. J. Agrometeorol. 20, 39–48.
Petralli, M., Massetti, L., Brandani, G., Orlandini, S., 2014. Urban planning indicators: useful tools to measure the effect of urbanization and vegetation on summer air temperatures. Int. J. Climatol. 34, 1236–1244.
Rahimi, J., Ebrahimpour, M., Khalili, A., 2013. Spatial changes of extended De Martonne climatic zones affected by climate change in Iran. Theory Appl. Climatol. 112, 409–418.
Reid, K., Oki, L.R., 2016. Evaluation of ornamental plant performance on four deficit irrigation levels: working with industry to promote sustainable plant choices for summer-dry regions, pp. 155–162. https://doi.org/10.17660/ActaHortic.2016.1112.22.
Robitu, M., Musy, M., Inard, C., Groleau, D., 2006. Modeling the influence of vegetation and water pond on urban microclimate. Sol. Energy 80, 435–447.
Romero, C.C., Dukes, M.D., 2010. In: Residential Benchmarks for Minimal Landscape Water Use. Agric. Biol. Eng. Dep. Univ. Florida UF Water Inst., Gainesville, FL, pp. 1–49.
Rosenfeld, D., 2000. Suppression of rain and snow by urban and industrial air pollution. Science 287, 1793–1796.
Salvador, R., Bautista-Capetillo Carlos, C., Playán, E., 2011. Irrigation performance in private urban landscapes: a study case in Zaragoza (Spain). Landsc. Urban Plan. 100, 302–311.
Shojaei, P., Gheysari, M., Myers, B., Eslamiyan, S.S., Shafieiyoun, E., Esmaeili, H., 2017. Effect of different land cover/use types on canopy layer air temperature in an urban area with a dry climate. Build. Environ. 125, 451–463.
Smeal, D., Clia, C.I.D., Neill, M.K.O., Lombard, K.A., Arnold, R.N., 2010. In: Climate-Based Coefficients for Scheduling Irrigations in Urban Xeriscapes, pp. 5–8.
Smith, M., 1992. CROPWAT: A Computer Program for Irrigation Planning and Management. Food Agriculture Org.
Snyder, R.L., 2010. Landscape Irrigation Scheduling Trends in California – From WUCOLS to LIMP 5–8.

Snyder, R.L., Eching, S.O., 2005. Microclimate corrections for urban landscape evapotranspiration. Impacts Global Clim. Change 1–9.
Snyder, R.L., Pedras, C., Montazar, A., Henry, J.M., Ackley, D., 2015. Advances in ET-based landscape irrigation management. Agric. Water Manage. 147, 187–197.
South Australian Water Corporation-IPOS Consulting, 2008. Irrigated public open space: code of practice. In: S. Water (Ed.), IPOS Consulting, South Australia, p. 46.
Spinti, J.E., St Hilaire, R., VanLeeuwen, D., 2004. Balancing landscape preferences and water conservation in a desert community. HorTechnology 14, 72–77.
Tabari, H., Aeini, A., Hosseinzadeh Talaee, P., Shifteh Some'e, B., 2011. Spatial distribution and temporal variation of reference evapotranspiration in arid and semi-arid regions of Iran. Hydrol. Process. Wiley. https://doi.org/10.1002/hyp.8146.
Takebayashi, H., Moriyama, M., 2007. Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. Build. Environ. 42, 2971–2979. https://doi.org/10.1016/j.buildenv.2006.06.017.
Thiessen, A.H., 1911. Precipitation averages for large areas. Mon. Weather Rev. 39 (7), 1082–1089.
Valiantzas, J.D., 2013. Simple ET0 Forms of Penman's equation without wind and/or humidity data. II: comparisons with reduced set-FAO and other methodologies. J. Irrig. Drain. Eng. 139, 9–19. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000502.
Valipour, M., 2015. Investigation of Valiantzas evapotranspiration equation in Iran. Theor. Appl. Climatol. 121, 267–278.
Waller, P., Yitayew, M., 2015. Irrigation and Drainage Engineering. Springer.
Wolf, D., Lundholm, J.T., 2008. Water uptake in green roof microcosms: effects of plant species and water availability. Ecol. Eng. 33, 179–186.
Yazdanpanah, N., 2017. Applying and development of LIMP model for urban landscape irrigation management (Case study: Isfahan city). M.Sc. thesis. Water engineering. Isfahan University of Technology, Iran.
Zhang, Y., Yang, Z., Fath, B.D., 2010. Ecological network analysis of an urban water metabolic system: model development, and a case study for Beijing. Sci. Total Environ. 408, 4702–4711.