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

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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

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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,