

# Chapter 16

## Determination of Net Water Requirement of Crops and Gardens in Order to Optimize the Management of Water Demand in Agricultural Sector



Hamidreza Salemi, Norair Toomanian, Amirhooshang Jalali,  
Alireza Nikouei, Morteza Khodaghali, and Moslehedin Rezaei

### Contents

16.1	Introduction .....	332
16.1.1	Problem Statement .....	332
16.1.2	Modeling Literature Review .....	334
16.1.3	Field Study .....	335
16.2	Materials and Methods .....	337
16.2.1	The Study Area .....	337
16.2.2	Site Description .....	338
16.2.3	Reference Evapotranspiration Calculation Method .....	340
16.2.4	Factors Determining the Crop Coefficient ( $K_{cb}$ and $K_c$ ) .....	341
16.2.5	Soil Data and Information .....	342
16.2.6	ETc: Crop Water Requirement .....	343
16.2.7	Agroclimatic Zoning of the Study Area .....	344
16.2.8	Creating an Intelligent Processing System .....	344
16.3	Results .....	345
16.3.1	ETo Outputs .....	345
16.3.2	Agroclimatic Zoning of Isfahan Province .....	346

---

H. Salemi (✉)

Agricultural Engineering Research Institute, Isfahan Agricultural and Natural Resources  
Research and Education Center, AREEO, Isfahan, Iran

N. Toomanian

Soil and Water Research Institute, Isfahan Agricultural and Natural Resources Research and  
Education Center, AREEO, Isfahan, Iran

A. Jalali

Horticulture and Crops Research Department, Isfahan Agricultural and Natural Resources  
Research and Education Center, AREEO, Isfahan, Iran

A. Nikouei

Social and Extension Research Institute, Isfahan Agricultural and Natural Resources Research  
and Education Center, AREEO, Isfahan, Iran

M. Khodaghali

Soil Conservation and Watershed Management Research Institute, Isfahan Agricultural and  
Natural Resources Research and Education Center, AREEO, Isfahan, Iran

16.3.3 Net Water Requirement .....	347
16.4 Conclusion .....	358
References .....	358

## 16.1 Introduction

### 16.1.1 Problem Statement

In Iran, the average annual precipitation is approximately 240 mm. However, it is temporally and spatially uneven distributed, therefore it does not optimally match the crops growing season's duration. Hence, water shortages are frequent, especially during the crop growing seasons. Iran, subjected to frequent droughts and water shortages, the water productivity of the agricultural sector must be improved by the management of existing water resources. Due to the lack of sufficient rainfall and unfavorable temporal and spatial distribution, Iran ranks among the arid and semi-arid countries in the world with serious water shortage problems (Keshavarz et al. 2005). This is compounded by a high population growth rate during the last four decades that has caused an increase in water demand for the limited water resources. The recent severe droughts caused by climate change in Iran brought forward many problems for agriculture. For example, production of rainfed wheat and barley dropped by 34–75% (OCHA 2001). Agriculture in Iran is highly dependent on irrigation water, as around 80% of agricultural product comes from irrigated crops (Salemi et al. 2011).

The high water demand of the agriculture and urban sectors in the study area, downstream of the ZRB (especially the Roodasht region) located in the central part of Iran; is intensified by the limited natural availability of water resources, arid conditions, and climatic variability. The main problem in the ZRB, particularly in the

---

M. Rezaei

Agricultural Engineering Research Institute, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran

Soil and Water Research Institute, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran

Horticulture and Crops Research Department, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran

Social and Extension Research Institute, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran

Rangeland Research Division, Rangelands and Forests of Institute Research, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran

Soil and Water Research Department, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Iran

upstream area, is the higher consumption of water resources where it provides a lower equitable contribution to economic development (Salemi 2012). Some of the general problems of the agricultural sector in such a study area can be summarized as follows:

Increased food demand due to growing population.

1. The amount of water allocated to the agriculture sector is likely to be reduced due to increasing domestic and industrial demand.
2. The main hydrological planning problem in these regions is due to limited water resources, which is aggravated by the arid condition rainfall and climate variability.
3. Climate change leads to Global warming, which consequently affects water resources, water and soil quality, soil moisture, evapotranspiration, rainfall frequency, type of precipitation and its intensity, and all of these, cause a permanent water shortage in the region directly or indirectly.

In recent years, due to the occurrence of frequent droughts and excessive water shortages in arid and semiarid regions, researchers' attention has been increasingly drawn to the determination of the net water requirement of plants at different phenological stages. Determining the exact timing of the phenological stages of plants allows us to manage the irrigation water (Bodner et al. 2015). Timing of phenological stages of plant growth are a major component in determining crop water requirements in a given area. The phenology of a plant is influenced by various environmental phenomena such as temperature, water availability, and photoperiod. Today, plant modeling is widely used in many sciences, such as climate change assessment (Menzel et al. 2006), and prediction of pest and disease outbreaks (Herms 2004), therefore, it is sometimes known as an integrative environmental science.

The effects of climate change on plant phenology, and in particular the impacts of temperature on these changes over the past decade have been considered. Crop water requirement and WP are those that are affected by climate change and generally lower crop production is expected with global warming due to the limited water supply (Chen et al. 2010).

Other modifying effects are changing the length of the growing period, variation in planting time, and altering cropping patterns (Keshavarz et al. 2010). The greatest concern of the Iranian farmers is the risk of water scarcity and drought (Keshavarz and Karami 2012). The negative effects of climate change are associated with economic and social problems. Unfortunately, small farmers receive the most damage in this regard.

Investigating the effects of climate change on crop water requirement in Iran's ZRB showed that crops water demand for wheat, barley, corn, and rice has been increased (Gohari et al. 2013). The maximum values of net water requirement increased 30.2% and 24.9% for rice and corn, respectively. Similarly, in China, an increase of 15.6–21.8% has been reported for irrigation water requirement of crop production due to warming effects on evapotranspiration under climate change (Tao and Zhang 2010). Other research has examined the effects of climate change on

wheat production in Iran. According to this research water deficits during the growing season (autumn to spring) in Iran's wheat-producing areas are expected to increase from 5.2% in 1980 to over 23% by 2050 and 38% by 2100 (Roshan and Grab 2012).

The current debate on climate change impacts on the water cycle has raised concerns regarding future water availability in Central and Northern European countries (Weatherhead and Knox 2000). In the Mediterranean regions, where conditions are expected to become warmer and drier over the next century, reduced rainfall, longer growth period, and delayed flowering and aging are expected (Llorens and Penuelas 2005). Such a profound change in the plant's phenology in dry and semiarid areas means an alarm for the supply and management of water resources. The accurate estimation of irrigation demands under current conditions is therefore a key requirement for better water management under climate change (Maton et al. 2005).

The dryland areas of the study region are characterized by considerable weather variability, as well as major environmental stresses, in particular drought and cold. Due to differentiation of agroclimatic diversity, zoning of different areas needs to take water management into consideration. In view of the very diverse climates, an agroclimatic zone map is of vital importance to achieve this purpose. In this way in this study, an agroclimatic zoning map is presented for better water management. Changes in crop water requirements and a holistic approach and zoning are needed.

Water saving using new irrigation systems and enhanced irrigation management is out-canceled by increases in cropping lands, hence appropriate solutions are necessary to limit water consumption for sustainable agriculture. Isfahan water authority allocates water allocation rights to farmers to manage water delivery (Anonymous 1993) that is the basis for estimation of irrigation water consumption. Nevertheless, there is no knowledge and accounting of irrigation water consumption in agricultural sector. Additionally, competition with irrigators' demand for water has intensified by accelerated population growth, industrialization, and urbanization. To efficiently manage the use of the available water resources to meet the possible variation of cropping patterns, studies of crop water requirements for crops and gardens based on dual coefficients are crucial.

The official organizations report (Anonymous 2005) claims that a portion of all abstracted water from aquifers and the Zayandeh Rud River is illegal and unrecorded. Exhaustive knowledge of irrigation water use is also missing in the Roodasht area, and due to the organizational complexity of public agencies in combination with private water supply companies, accounting for total water sources is out of control of water authority (such as Mirab Company).

### ***16.1.2 Modeling Literature Review***

Deterministic models have been developed to estimate crop irrigation needs for assisting irrigation scheduling and water resources management (Wriedt et al. 2009).

In this section, only a few studies that relate to the current study were assigned. Bastiaanssen et al. (2007) provided a complete review on the irrigated crops modeling which focuses on some examples of model applications and technical improvements.

Ramazani-Etedali et al. (2009) applied the CROPWAT model to simulate wheat and barley yield reduction caused by water stress under semiarid conditions in the Karaj Province in Iran. Toda et al. (2005) believed that because the CROPWAT model did not take into consideration different water stress types and the effects of crop response, it is necessary to include these aspects for improved accuracy when estimating dry season irrigation.

Irrigation strategies should be carefully chosen to optimize crop productivity, while guaranteeing the sustainability of agriculture. Todorovic et al. (2009) found out that AquaCrop performed similarly to CropSyst and WOFOST when simulating the water use and yield of sunflowers, but in WP simulation was much better under a limited water supply. CropSyst had a limiting factor in severe water deficit conditions due to utilizing crop growth modules that could be affected by climatic characteristics. Heng et al. (2009) showed that the AquaCrop model performed suitably for the water requirements of maize and grain yield in the non-water-stress treatments and mild stress conditions. But it was less satisfactory in simulating severe water-stress treatments, particularly when stress occurred during senescence. The authors believed that the effect of severe water stress needs more assessment. Araya et al. (2010) found that the AquaCrop model is valid to simulate barley water accounting and crop yield under various planting dates in Ethiopia. The model could be used in the evaluation of optimal planting time and irrigation scheduling. In this study, barley showed somewhat lower performance under mild water-deficient conditions compared to full irrigation treatment. Farshi (1997) and Alizadeh and Kamali (2007) used the standard modeling approach based on the FAO guideline estimated crop water requirement for selected provinces of Iran. They concluded in accounting water need studies involving all provinces of Iran, that information instruments in all surveyed provinces were considered to be inadequate or to have deficits, resulting in poor knowledge on accounting of the real water use by the agriculture sector. These issues create ambiguity in the accuracy and consistency of reported data.

### ***16.1.3 Field Study***

A field study is needed to provide the basic data required for irrigation water management. Silage maize, wheat, barley, sorghum, onion, potato, and cotton as annual crops and orchards including olive, grape, pistachio, and pomegranate are perennial crops in the region and are planted in the agricultural areas for many years. For mentioned crops, field experiments have been performed to develop economic techniques to save agricultural sector's water resources.

Isfahan researchers promoted on-farm water balance as the regular method for determining how much water to apply per irrigation. In order to illustrate the impacts of water deficit on yield and some agronomic characteristics of wheat, a study by Salemi and Afyuni (2005) was conducted as randomized complete blocks design with a split-plot layout and three replications during 3 years (2001–2002, 2002–2003, 2003–2004) in Kabutarabad Agricultural Research Station, Isfahan. Three levels of irrigation including 60, 80, and 100% of water requirements were considered as the main plots and six wheat cultivars as subplots. In this study, Pishtaz cultivar was used as the recommended cultivar for the dry regions.

In the same location, a similar experiment (Mahluji et al. 2006) was conducted on the barley genotype (Karron  $\times$  Kavir, Valfajr, M-79-4, M-79-7, and M-79-15) during two growing seasons (2003–2004 and 2004–2005) with four irrigation levels in three replicates. Additional field trials were conducted with five irrigation levels of 100%, 90%, 80%, 70%, and 60% of full water requirement in three replicates, respectively (Salemi et al. 2017).

In another experiment, the effects of various water consumptive levels on yields of maize were studied in a randomized complete blocks design using a split-plot layout for 3 years. The short season, maze variety (the single cross 647) was planted in this experiment at the research station (Salemi 2012).

The effect of soil moisture stress at early growth stages on yield and tuber size of commonly grown four potato cultivars (*Marfona*, *Concord*, *Agria*, and *Cosima*) was studied in an experiment in the 2006 and 2007 growing seasons. The plots were arranged in split-plot with a randomized complete block design with five irrigation treatments replicated three times (Jalali et al. 2017).

To study the effects of irrigation regimes on the bulb yield of onions, an experiment was conducted during two growing seasons (2012 and 2013) (Salemi 2013). The experiment design was Split-Factorial with a randomized complete block arrangement and four replications. The main plots included three irrigation regimes based on evaporation from class A pan and subplots of a factorial combination of two spring onion genotypes (Sweet Spanish and Dorcheh).

An experiment was conducted on a cotton farm at Kabutarabad Research Station (Jafaraghaei and Deghani 2010) to study the effects of four applications of irrigation water on cotton yield (Tabladila and B-557 cultivars). The experimental design was a complete randomized block with four replications and was conducted in 2 consecutive years (2003–2004).

The results show that regarding the irrigation water requirements for Silage maize, wheat, barley, sorghum, onion, potato, and cotton are 728, 606, 522, 620, 922, 650, and 1150 mm, respectively.

The NWR (Net Water Requirement) model estimates the crop water need in the Roodasht area and validated using meteorological and crop data from experimental fields run by the Isfahan Agricultural Research, Education and Extension Organization. It is believed that policy makers should carefully choose crops and irrigation strategies to maximize the value of the crop yield, while guaranteeing the sustainability of water supply.

The purpose of creating databases and intelligent processing of information is to provide the final output of the project (net water requirements) as follows:

- Provide a basic and upgradable database of soil, climate, and cultivated crops.
- Preparation of calculation algorithm based on output from upgraded database.
- Preparation of dynamic and permanent maps related to net water requirement by the studied plants.
- Generate dynamic reports of net water demands in hydrological and political geographical boundaries.

The scope of this study includes:

1. Selection of the Roodasht region as a major river sub-basin in the ZRB with adequate agronomic and climatic data.
2. Collecting of hydrological and meteorological data, crops, soils, farming practices, and economic data, for the database.
3. Determining the parameters required as input data set for running the simulation and optimization models.
4. Calculating net irrigation water requirements using the NWR model (without any crop water stress).

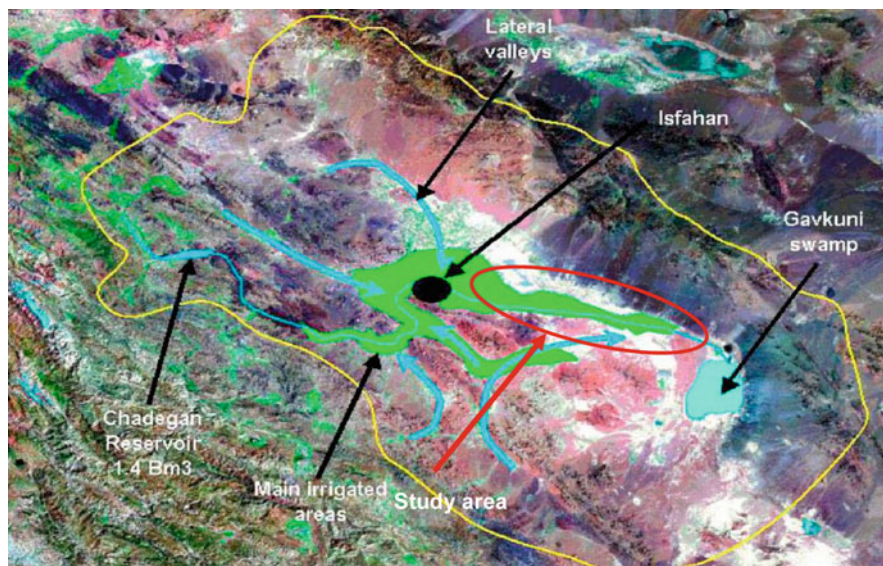
This project focused on the opportunities for improving agricultural water management through accounting of precision irrigation water requirements. This is a multidisciplinary and integrated approach involving irrigation engineers, soil scientists, agronomists and plant physiologists, and computer experts.

## 16.2 Materials and Methods

To develop a suitable and practical NWR, various data sets including land suitability and farm information are required. We applied the NWR model by including the crop growth, climate, soil, and irrigation sub models to calculate NWR in the ZRB and Roodasht. Available regional statistics on crop distribution and crop cultivation areas with spatial data sources on soils, land use, and climate were integrated. The required information in a systematic process was summarized and processed into a database for running the NWR mathematical model.

### 16.2.1 *The Study Area*

The Zayandeh Rud River (literally, the river that renews itself) has been the lifeblood of central Iran for centuries, focused around the ancient city of Isfahan. In 1600 AD, Isfahan was one of the ten largest cities in the world, sustained by irrigated agriculture and the flows of the Zayandeh Rud River. The city remains the cultural heart of Iran. In this section, an overview of the river basin is provided that helps to put more



**Fig. 16.1** Layout of the ZRB and the location of the study area

detailed information into perspective. The ZRB (Fig. 16.1) has for centuries provided the basis for important economic activities. These activities can be categorized into three sectors including agricultural, industrial, and domestic consumptions. Numerous water projects have been constructed, are under construction or under the study for the basin. The dam is the main water reservoir with 1500 MCM capacity and has been operating since 1971 (Salemi et al. 2011). Modern surface irrigation started in the 1970s with the completion of the Chadegan reservoir and the construction of major diversion dams that serve to regulate the water supply to six irrigation networks namely Lenjanat, Nekooabad, Abshar, Borkhar, Mahyar, and Roodasht (Fig. 16.1). The most part of the ZRB located in the east of Isfahan city along with the Roodasht area is considered as the study area.

The Roodasht irrigation project ( $52^{\circ}$  lon.  $32.5^{\circ}$  lat.) is located east of Isfahan in the central part of Iran and has an altitude of approximately 1500 m (Fig. 16.2). The climate is arid with temperatures ranging from  $35^{\circ}\text{C}$  in summer down to  $3^{\circ}\text{C}$  in winter. Average annual precipitation is 100 mm. Soils in the area are alluvial deposits and are fine textured, which will result in a total command area of approximately 47,000 ha (Droogers and Torabi 2002).

### 16.2.2 Site Description

The basin's general soil map is shown in Fig. 16.3. It is evident that in two major subbasins the major soil class is clay while loam is the dominant soil type in other

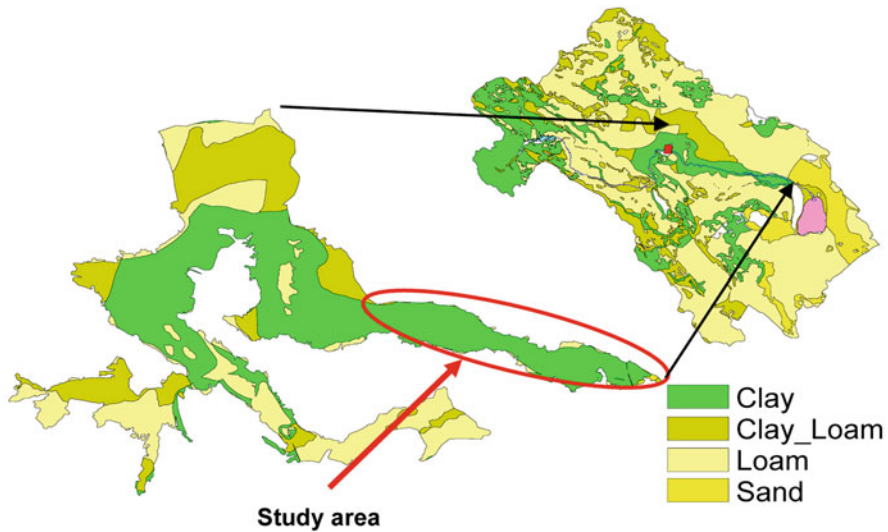




Fig. 16.2 Location of the Roodasht area in the Esfahan region, Iran

subbasins (Anonymous 1998). The figure also shows the soil texture classes of the major irrigation network.

Agriculture is the dominant water user that consumes around 80% of the river yield. However, there has normally been inadequate water to irrigate the total cropped area. Many cropping alternatives are available to farmers in this area. Typically, there is a two-season cropping pattern in all of the irrigation systems on the eastern side of the ZRB. Summer crops include potato, onion, cotton, sorghum, and maize while winter crops are dominated by wheat and barley. In addition, there are some perennial crops, including orchards with olive, grape, pistachio, and pomegranate. Wheat, rice, barley, fodder, and potato are the main staple crops in the basin (Anonymous 1993). The irrigation season commences on 1 April and reservoir releases remain more or less constant from May, June to August. It is only in the later parts of the irrigation season (August to September) that discharges are decreased as demand drops. The providing of more water with timing better suited to the needs of higher value crops has clearly been highly beneficial and productive at basin level and for the upper portions of the ZRB. Yet it has had severe effects on the groundwater problems in the tail part of the river basin, which has led to greatly



**Fig. 16.3** The general soil map of the ZRB and study area (source: Droogers and Torabi 2002)

increased inequity in production and incomes between head and tail end parts of the basin. Recently, due to the intensification of the water crisis along the entire ZRB, no water has been allocated to the Roodasht area. Annual cropping intensity is about 85% and is slightly higher for summer than winter crops. The cropping pattern is dominated by wheat (62%) and barley (9%). No other crop exceeded 10% of the total irrigated area. These cropping patterns are typical of current practices still found in the lower parts of the basin and throughout Roodasht.

### ***16.2.3 Reference Evapotranspiration Calculation Method***

Many methods are available for estimating reference evapotranspiration ( $ET_0$ ). The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as  $ET_0$ . The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions. Radiation, modified Penman, Blaney–Criddle, and Pan-evaporation, have been broadly applied in different climatic conditions to calculate  $ET_0$ . DehghaniSanija et al. (2004) found the Penman–Monteith model as the most reliable method, compared to lysimetric data, for Karaj region, in Iran. Mostafazadeh-Fard et al. (2009) determined crop coefficient and evapotranspiration for a reference crop of grass and for two typical landscape trees of Ash and Cypress using field drainage lysimeter in an arid region of Isfahan in the

central part of the country. They demonstrated that the Penman–Monteith FAO 56 method showed good agreement with the lysimeter data. The relatively accurate and consistent performances of the Penman–Monteith approach in both arid and semiarid climates have been indicated in both the American Society of Civil Engineering and European studies (Allen et al. 1998).

In the first stage, reference evapotranspiration was calculated based on the FAO Penman–Monteith method using effective parameters by a climate sub-model of the NWR model. This method is the most general and widely used equation for calculating daily reference ETo that is recommended by FAO. Using the Kriging method in GIS environment ETo zoning 13680-time series of temperature and 13680-daily time series of evapotranspiration was simulated for 24 districts and 59 major plains. The spatially distributed implementation covers the Roodasht on a 7 by 7 km grid and the ZRB. The ETo was calculated by applying NWR climate sub-model. In NWR model the ETo, is atmosphere evaporative demand. The inputs for the calculator such as [maximum air temperature ( $T_{max}$ ), minimum air temperature ( $T_{min}$ ), maximum relative humidity (RH $_{max}$ ), minimum relative humidity (RH $_{min}$ ), sunshine hours ( $n/N$ ), and wind speed at a height of 2 m ( $u_2$ ) based on long-term weather data (1979–2017) were collected at Kabutarabad station (51.83 lon. 32.5° lat.). Daily reference evapotranspiration was obtained by the Penman–Monteith model (Allen et al. 1998):

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \left( \frac{900}{T+273} \right) \mu_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 \mu_2)} \quad (16.1)$$

where  $R_n$  is the net radiation ( $\text{MJ m}^{-2} \text{ day}^{-1}$ ),  $G$  the soil heat flux density ( $\text{MJ m}^{-2} \text{ day}^{-1}$ ),  $T$  the air temperature at 2 m height ( $^{\circ}\text{C}$ ),  $u_2$  the wind speed at 2 m height ( $\text{m s}^{-1}$ ),  $e_s$  the saturation vapor pressure (kPa),  $e_a$  the actual vapor pressure (kPa),  $e_s - e_a$  the saturation vapor pressure deficit (kPa),  $D$  the slope of the vapor pressure curve ( $\text{kPa } ^{\circ}\text{C}^{-1}$ ), and  $\gamma$  the psychrometric constant ( $\text{kPa } ^{\circ}\text{C}^{-1}$ ).

The main menu of the climate module is composed of three sections of database management, selected climatic station, and ETo calculation. The climatic parameters are used to calculate ETo, meteorological records can be updated, specified and plotted, and results can be exported into an irrigation sub-model.

#### **16.2.4 Factors Determining the Crop Coefficient ( $K_{cb}$ and $K_e$ )**

Typical crop coefficients, calculation procedures for adjusting the crop coefficients and for calculating crop evapotranspiration are presented in this section. There are two calculation approaches: the single and the dual crop coefficient approach. Differences in evaporation and transpiration between the cropped and the reference grass surface can be combined into one single crop coefficient ( $K_c$ ) or separated into

two coefficients: a basal crop ( $K_{cb}$ ) and a soil evaporation coefficient ( $K_e$ ) according to the FAO method.  $K_{cb}$  of FAO was obtained during a field visit and Eq. (16.2)  $K_e$  was calculated from soil physical properties, irrigation intervals, and irrigation depth ( $K_c = K_{cb} + K_e$ ). As discussed in the FAO report No. 56 (Allen et al. 1998), the single crop coefficient approach is used for most applications related to irrigation scheduling, strategy, and management. The dual crop coefficient approach is related to detailed estimates of calculations of soil water evaporation, such as in real-time irrigation scheduling applications.

The growing period can be divided into four distinct growth stages: initial, crop development, mid-season, and end season. The changing physiological characteristics of each crop or tree over the growing season affect the  $K_c$  coefficient. Evaporation as a non-benefit part of crop evapotranspiration is soil evaporation and effect  $K_c$ . Crop coefficients are dynamic parameters in time and space. The dynamicity of these coefficients is due to ever changing used plant cultivars and species, differences in climate conditions and changes in each region, and dynamism of plant growing seasons due to environmental conditions. These facts reflect the difficulty of crop coefficient application in crop pattern developing programs every year in, yet, a single location (Kuo et al., 2006).

For specific adjustment in climates where  $RH_{min}$  differs from 45% or where  $u_2$  is larger or smaller than 2.0 m/s, the  $K_c$  mid-values are adjusted as:

$$K_{cb} = K_{cb(FAO)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)] \left(\frac{h}{3}\right)^{0.3} \quad (16.2)$$

where  $u_2$  is the mean value for wind speed at 2 m height during the mid-season (m/s);  $RH_{min}$  is the mean value for minimum daily relative humidity (%) during the midseason; and  $h$  is the average plant height (m). Typical values of  $K_{cb \text{ mid}}$  for non-stressed conditions in subhumid climates are provided by Allen et al. (1998) and the  $K_{cb}$  was calculated for estimation of the crop water evapotranspiration.

### 16.2.5 Soil Data and Information

To infer soil data and information in net water demand calculations and describing the presented map layouts, three kinds of soil data were used in this study.

- Choropleth maps of soil characteristics mapped based on land units produced for Isfahan province.
- Quantitative soil data extracted from the Isfahan Soil Database (prepared by authors).
- Analyzed soil samples texture, field capacity, and wilting point taken from soil Ap horizon during the field visits.

Some selected soil data in this project were calculated as follows:

- From the Choropleth maps the polygon map of soil types, depth, texture, sand, silt, clay, OC, EC, gravel, and land arability classes are produced.
- Using an additional 1600 soil profile available data, the texture, amount of sand, silt, clay, OC, and EC in two surficial soil layers were interpolated with geostatistical techniques (Toomanian 2016).
- Selecting 204 representative fields of crops and orchards well spread throughout the entire province, disturbed, and undisturbed soil samples were sampled from the surface layer. Soil moisture and bulk density ( $\rho_b$ ) of undisturbed samples were measured ( $\rho_b$  were corrected based on the amount of gravel in soils). Soil salinity, texture, amount of sand, silt and clay, OC, gravel, and  $\theta_w$  (weighted moisture) of soil FC and PWP of disturbed soils were also determined.
- Having  $\theta_w$  and  $\rho_b$ , the  $\theta_v$  (volumetric moisture) of soil samples was calculated (Hillel 1980) using the USDA model, the  $\rho_b$  of all profile points was calculated.
- A pedotransfer function was extracted by relating the  $\theta_v$  and soil physical parameters (which were all geographically mapped in the study area). This was used to calculate the raster map of  $\theta_v$  in the study area.

### 16.2.6 *ETc: Crop Water Requirement*

Accurate estimation of  $ET_c$  in cultivable lands is necessary for improving irrigation scheduling and efficient use of water resources. The most commonly used method for calculating water demand (crop evapotranspiration,  $ET_c$ ) is a two-step approach that calculates  $ET_c$  from  $ET_o$  and crop growth through the  $K_c$  coefficient (Allen et al. 1998).

The daily  $ET_o$  is used to calculate the crop evapotranspiration under standard conditions (Kuo et al. 2006), as given by.

$$ET_c = (K_{cb} + K_e) ET_o \quad (16.3)$$

where  $ET_c$  is the crop evapotranspiration ( $\text{mm day}^{-1}$ ) under no soil water stress with adequate soil fertility. At this stage of study, the NWR model is used to calculate  $ET_c$  and net water requirement during the growing season for each decade in a corresponding month, considering data such as crop coefficient, canopy cover index, crop evapotranspiration, and effective rainfall.

According to the available data, the sub-model irrigation of the NWR model, estimates effective rainfall by the soil conservation service (SCS) relationship. The part of precipitation that directly meets the water need of a plant is called the effective rainfall. Khaleghi (2016) reported that in arid and semiarid areas, the SCS provides more reliable values. Net irrigation requirements per hectare are calculated as the difference between the crop evapotranspiration and effective precipitation.

### ***16.2.7 Agroclimatic Zoning of the Study Area***

The dryland areas of Iran are characterized by considerable climate variability, as well as major plant physiological stresses, in particular drought (Ghaffari et al. 2015). Hence an agroclimatic zone (ACZ) map is of vital importance to achieving an applicable approach that provides useful information such as crop suitability for decision makers on a study area scale. The aim of this part of the study is to present agroclimatic zoning differences for crop suitability usages and to indicate easily available information to users and decision makers.

Data of monthly averages of precipitation, temperature, relative humidity, total incoming solar radiation, and wind speed from the main stations (31 synoptic weather stations) were collected in the province from 1978 to 2017 and analyzed by using the UNISCO approach (Ghaffari et al. 2015). Finally, map zoning (ACZ) on the basis of the three criteria: moisture regime, winter type, and summer type provided a total of five agroclimatic zones in regional scale.

### ***16.2.8 Creating an Intelligent Processing System***

In order to create an intelligent processing system for provincial water information and to achieve the objectives of this study, a system called “Net Water Requirements Database of Plants in Isfahan Province” was designed and implemented. In this database, the necessary forms for loading all primary information were designed and implemented. In addition, computational algorithms based on the methodology provided by other study groups (soil, water, and plant study groups) for the intelligent processing of these data and calculations related to the water requirement of the studied products were developed and implemented to produce raster maps of each crop. The expected outcomes were also defined in the program. This system allows the users at levels of the researcher, expert, manager and planner, and even the agricultural operator to produce the results as per their will.

In the last part of the study, the combination of field—river basin scale models (NWR) and GIS methods allows estimating irrigation water demands in irrigation districts at a regional scale. This model is linked to a spatial database containing information connecting the soils, weather, and crop physiologic stage, irrigation parameters, and cultivated crop areas for each grid cell. The net irrigation requirements for each 5 climate zone, and for the 11 dominant crops within each grid cell, were calculated using the NWR auto-irrigation model.

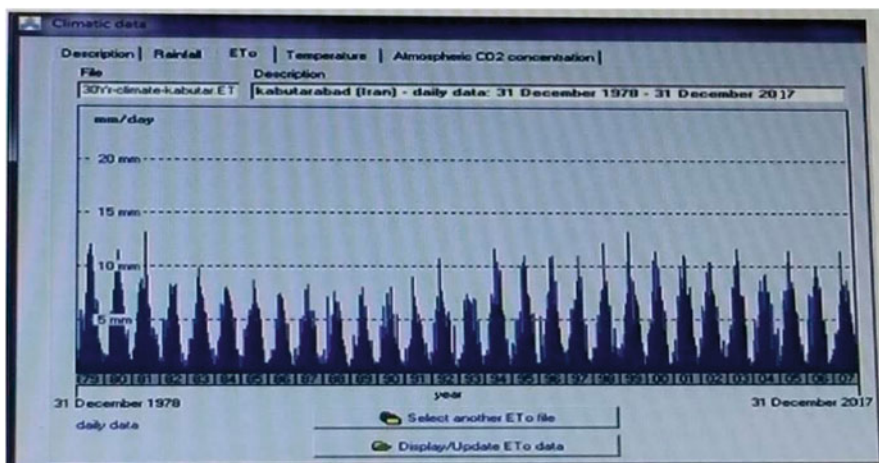


Fig. 16.4 ETo computed from daily meteorological data for Kabutarabad station (1978–2017)

## 16.3 Results

Based on what had been explained in the methodology section, the results of model output and their associated discussion of processes are presented in this section. In this section of the study ETo, ETc, and net irrigation requirements for each cell and crop are determined and presented.

### 16.3.1 ETo Outputs

ETo was derived from the long-term Kabutarabad weather station's data (20 km east of Isfahan city) data by FAO Penman–Monteith equation for the Isfahan city presented in Fig. 16.4. In the study area, the ETo rises to 13.6 and 14.8 mm day<sup>-1</sup> in late May and mid-July, respectively. In the ETo calculator sub-model, the data from a weather station was specified in 11 crop seasons, meteorological data was imported and the calculated ETo was exported to the NWR model.

The total ETo in long-term mean decade (1978–2017) was 1609 mm compared with 1639 mm in 2017. The long-term mean decade ETo was computed for all months and stations. However, iso-ETo curves for each of the 11 active crop growth months, March–October, were illustrated (Fig. 16.5) on Isfahan province's map. It was found that the pattern of these curves is considerably similar from decade to decade. The rate of change of ETo varied from month to month. The monthly ETo increased from April to August, however, the rate of increase was faster than previous (April to June) months. Figure 16.5 shows the long-term mean annual ETo isopleths of the study area. The mean annual ETo for over 30% of the province's area was more than 2000 mm. In the same way, for about half of the province's area

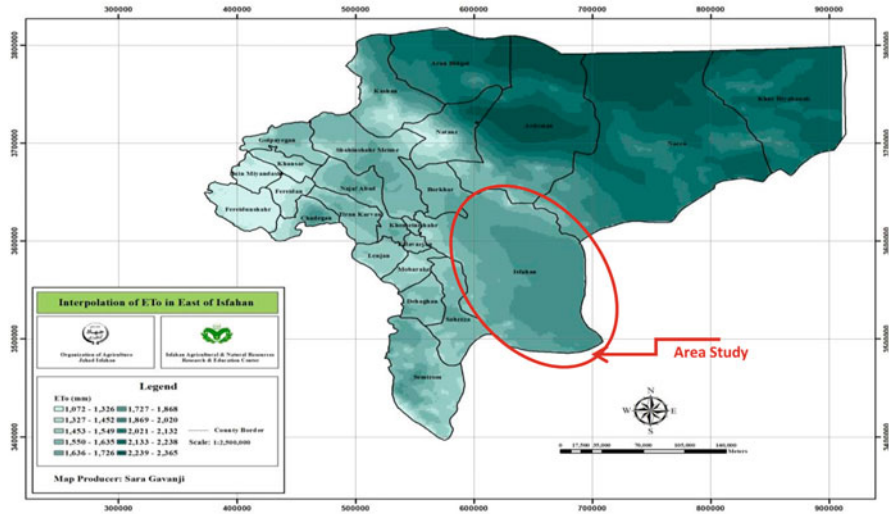


Fig. 16.5 Mean decade ETO (mm) in Isfahan city (1978–2017)

the mean annual ETo was more than 1470 mm. The mean annual ETo of Isfahan province varied between 1219 mm in the Booien-Miandasht station, located in the west, and up to 2027 mm in the Khoor-Beeyabanak station, located in the eastern part of the province.

### 16.3.2 Agroclimatic Zoning of Isfahan Province

Data of monthly averages of precipitation, temperature, relative humidity, total incoming solar radiation, and wind speed from the main stations (31 synoptic weather stations) were collected in the province from 1978 to 2017 and analyzed by using the UNISCO approach. Finally, map zoning (ACZ) on the basis of the three criteria: moisture regime, winter type, and summer type provided a total of five agroclimatic zones in region scale containing Arid-Cool A-C-VW, A-C-W, A-K-W, SA-C-W, and SA-K-W.

The agroclimatic zones map of Isfahan province has been obtained from one of the outputs of the study (Fig. 16.6). The classes were created using a program written in Visual Basic. The ACZ map is of vital importance to achieving an applicable approach that provides vital information such as crop suitability for decision makers on a study area scale.



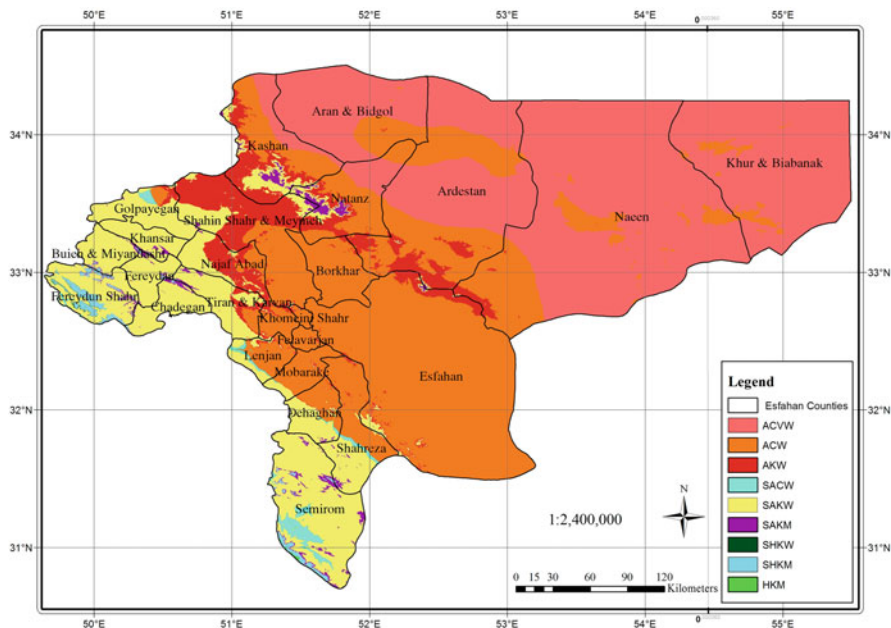


Fig. 16.6 Agroclimatic zones

### 16.3.3 Net Water Requirement

This part focuses mainly on NWR results which can be used as a useful tool for irrigation water demand analysis and deficit irrigation implementation in agricultural water management in study areas east of the river basin.

To compute the net water requirement for the seven crops during the growing season, the irrigation schedule is defined on the basis of fixed intervals (time criterion) between irrigations (overall 7–8 days) and back to soil field capacity options as depth criterion was considered. Model output was presented at 10-day intervals (i.e., decade). After completing the data entry by other information groups using the implemented algorithms, the ETo reference, the plant’s net water requirement (ETc, effective rainfall), and finally the irrigation requirement was calculated and mapped as geographic raster outlines.

These maps were produced for 36 decades for 1987–2017 growing session. Raster maps of net water requirements are reported, and all calculated data and information are produced in five climatic zones. The decade water requirement for

**Table 16.1** Calculated irrigation water requirement of wheat in the region

Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
11	2	10.5	0	10.5	0	0
11	3	5.7	0.3	6	1	0
12	1	1.4	1	2.4	0	0
12	2	2.2	1.5	3.6	0	2.6
12	3	6.5	3.7	9.8	0	9.8
1	1	5.4	4.8	10.1	0	10.2
1	2	3.2	4.7	8	0	7.7
1	3	3.9	10.3	14.2	0	15.3
2	1	5.2	14.5	19.7	5.1	14.1
2	2	2.5	18.5	21	0	20.4
2	3	2.7	21.4	24.1	1	25.4
3	1	3.2	27.1	30.3	3.6	27.5
3	2	3.6	32.1	35.8	6.4	29.2
3	3	2.2	33.7	35.8	0.6	33.5
4	1	1.7	28.1	29.8	3	25.7
4	2	1.9	30.2	32.3	0	34.4
4	3	2.8	49.7	52.6	10	43.2
5	1	2.4	49.7	52.2	1	53.9
5	2	2.9	54.6	57.4	2	55.2
5	3	4.3	57.2	61.7	0.10	59.5
6	1	6.2	32.9	39	0	38.8
6	2	10	6.2	16.4	2.8	14.4
Total		91	483	574	38	520.8

E: Evaporation, Tr: Transpiration

the annual crops is given in Tables 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, and 16.7 where E is evaporation from the soil and Tr is the crop transpiration, decade is the three 10-day intervals of the month.

In addition, the ETc, rain effect, and NWR during the growing season were estimated using the NWR model for the four garden crops at the study locations. In the pomegranate, pistachio, grape, and olive gardens, the net water requirements during the growing session resulted in 908, 703, 728, and 512 mm, respectively. To validate the results' net water requirement, experimental data, the irrigation management model was applied for estimating crop water requirements and upgrading irrigation management for the 11 crops east of the ZRB.

There are two distinguished cropping seasons in a year in the study area: the summer season and the autumn season. In the summer season, all crops need irrigation water from April to October. In order to allocate irrigation water to each crop, the value of net monthly water requirement for all productions per unit area is

**Table 16.2** Calculated irrigation water requirement of barley in the region

Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
11	2	10.6	0	10.6	0	5.1
11	3	2	1.8	3.8	1.2	2.6
12	1	3.8	1.4	5.1	4.5	3.4
12	2	2.7	2.7	5.3	5.4	0
12	3	3.1	2.5	5.6	12	0
1	1	2.8	2.7	5.7	12.2	0
1	2	3.4	3.8	7.2	12.1	0
1	3	2.6	10.3	12.9	4.6	7.3
2	1	2.3	14.4	16.7	3	5.7
2	2	2.8	25.2	27.9	1.2	25.0
2	3	1	26.1	27.1	0	21.5
3	1	2.1	40.7	37.7	3.3	31.2
3	2	1.1	34.7	30.7	5.7	25.6
3	3	1.5	48	44.6	0	44.8
4	1	1.7	43	40.7	11.3	30.9
4	2	1.8	41.4	38.2	12.6	30.9
4	3	1.2	53.1	49.2	4	45.5
5	1	1.8	62.9	58.8	1.7	55.5
5	2	3.7	63.3	62.0	0	62.8
5	3	8.5	20.2	28.5	0	28.5
Total		62.5	498.2	518.3	92.8	426.5

**Table 16.3** Calculated irrigation water requirement of silage maize in the region

Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
6	1	22.4	0.3	22.6	0	9.2
6	2	34.6	2.5	37.1	0.5	24.9
6	3	33.6	7.4	40.7	0	42.4
7	1	30.1	41.3	71.3	0	71.6
7	2	10	77.5	87.5	0	88.1
7	3	3.3	98.7	102.1	0	102.2
8	1	2.3	94.7	97.2	0.6	93.9
8	2	2	87.6	89.5	0	88.4
8	3	3.1	77.7	80.8	0	81.5
9	1	8.2	48.6	57	2.2	55.4
9	2	5	4.6	9.6	0.3	7.1
Total		164.6	545.9	710.4	3.6	665.7

**Table 16.4** Calculated irrigation water requirement of *Sorghum* in the region

Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
6	1	10.4	0.3	10.7	0	10.2
6	2	28.6	2.5	31.1	0.5	30.9
6	3	27.6	7.4	35.0	0	35.4
7	1	24.1	26.3	50.4	0	50.4
7	2	4	62.5	66.5	0	66.1
7	3	3.3	83.7	87.0	0	86.2
8	1	2.3	79.7	82.0	0.6	81.9
8	2	2	72.6	74.6	0	74.4
8	3	3.1	62.7	65.8	0	65.5
9	1	2.2	33.6	35.8	2.2	33.4
9	2	2	4.6	6.6	0.3	6.1
Total		110.0	445.9	564.4	4.4	540.0

**Table 16.5** Calculated irrigation water requirement of potato in the region

Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
4	1	10.1	0	10.1	0	0
4	2	14.9	0	14.9	4.3	0
4	3	9.6	0.4	10	0.2	12.5
5	1	22.7	3.4	26	0.2	22.9
5	2	25.9	10.6	36.7	0	33.9
5	3	18.5	30.4	49	0.8	51.1
6	1	5.7	44.7	50.5	0	43.1
6	2	1.4	45.9	47.2	0	50
6	3	0.1	51.1	51.2	0	44.9
7	1	0	51.7	51.7	0	48.8
7	2	0	56	56	0	52.6
7	3	0	51.9	51.9	0	54.2
8	1	0	44.4	44.4	0	45.2
8	2	0	41.5	41.5	0	41.9
8	3	0	45	45	0	46.8
Total		108.9	477	586.1	6	547.9

illustrated in Table 16.8. The evapotranspiration for winter wheat crop was the lowest (426.5 mm) and the summer crop onion was the highest (1107.7 mm).

Graphical displays of local average crop water requirement for 11 crops in the period 1978–2017 are shown in Figs. 16.7, 16.8, 16.9, 16.10, 16.11, 16.12, 16.13, 16.14, 16.15, and 16.16.

**Table 16.6** Calculated irrigation water requirement of onion in the region

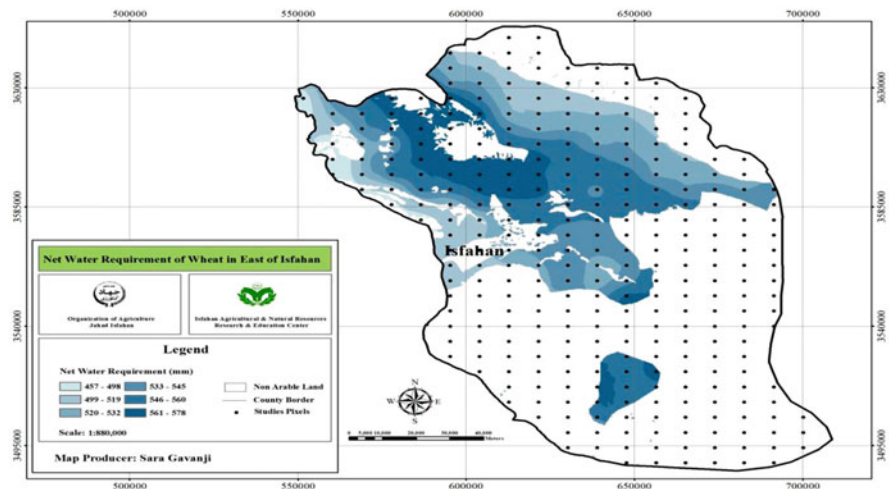
Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
3	1	13.2	0	13.2	0	0
3	2	25.6	0.5	25.9	2.9	23.8
3	3	43.2	1.4	44.7	7.8	36
4	1	37.1	2.5	39.8	0.2	39.8
4	2	35.4	5.4	40.9	1	41.5
4	3	38.6	11.4	50	1.7	48
5	1	37.8	23.5	61.1	0	62.2
5	2	30.6	40.6	71.2	0	70.7
5	3	22.7	50.2	73.1	1	72
6	1	22.9	63.7	86.4	0	86.4
6	2	20.3	65.4	86.1	0.2	86.7
6	3	22.3	75.7	98	0	96.5
7	1	22.1	78	100.2	0	101.9
7	2	20.3	72	92.2	0	92.5
7	3	20.9	74.7	95.6	0	94.3
8	1	17	60.9	77.7	0	78.2
8	2	19.3	46.6	65.6	0.3	64.5
8	3	19.6	3.2	22.7	0	12.7
Total		468.9	675.7	1144.4	15.1	1107.7

**Table 16.7** Calculated irrigation water requirement of cotton in the region

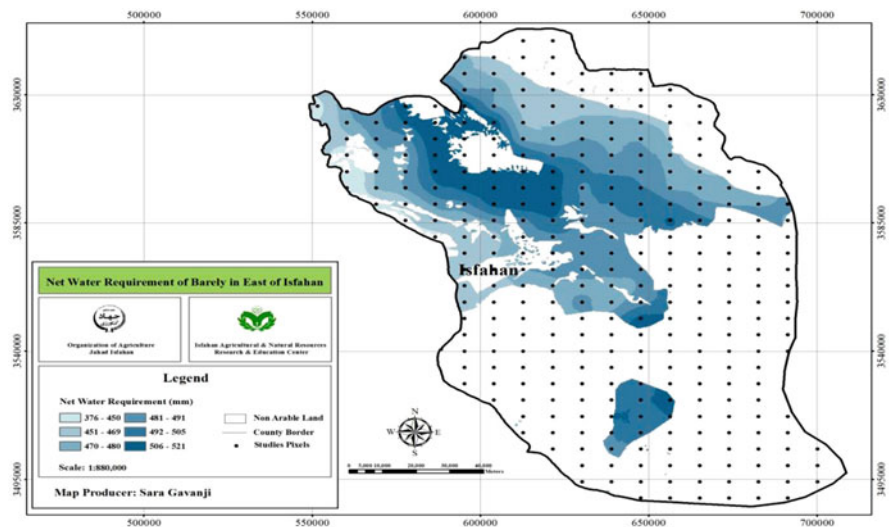
Month	Decade	E (mm)	Tr (mm)	ET (mm)	Rain (mm)	NWR (mm)
5	1	9.4	0	9.4	0	0
5	2	7.8	0.1	7.9	0.2	4.3
5	3	19.8	1.8	21.5	0	18.3
6	1	20.3	3.4	23.6	0	20.7
6	2	22.3	8.2	30.5	0	30.2
6	3	18.1	15.6	33.8	0	33.2
7	1	16.6	29.5	46.3	0	42.8
7	2	11.1	52.5	63.5	0	65.2
7	3	7.5	98.6	105.9	0	108.6
8	1	3.3	92.6	96.2	0	90.2
8	2	2	88.7	90.7	0	91.8
8	3	1.2	86.7	88.3	0	86.3
9	1	0.9	68.7	69.3	0	70.9
9	2	1	73.9	74.8	0	71.2
9	3	0.8	57.8	58.4	0	59.3
10	1	1	53.1	54	0	50.1
10	2	0.6	25.1	25.4	0	25.6
Total		143.7	756.3	899.5	0	869

**Table 16.8** Monthly water requirement (mm) for main crops in study area

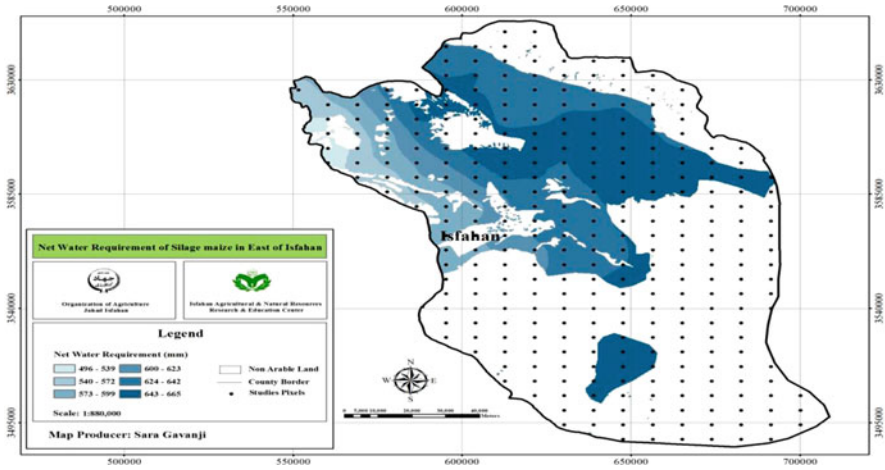
Crop	Net water requirement (mm)											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Wheat	0	0	12.4	33	60	90.2	103.3	168.6	53.2	0	0	0
Barley	0	7.7	3.4	7.3	52.2	102	107.3	146.5	0	0	0	0
<i>Sorghum</i>	0	0	0	0	0	0	0	76.6	202.8	221.7	250.6	39.6
Silage maize	62	0	0	0	0	0	0	0	91.5	261.9	263.8	0
Potato	0	0	0	0	0	0	12.5	107.9	138	155.6	133.9	0
Onion	0	0	0	0	0	59.7	129.3	204.9	269.6	288.7	155.5	0
Cotton	75.	0	0	0	0	0	0	22.6	84.1	216.6	268.3	201.7



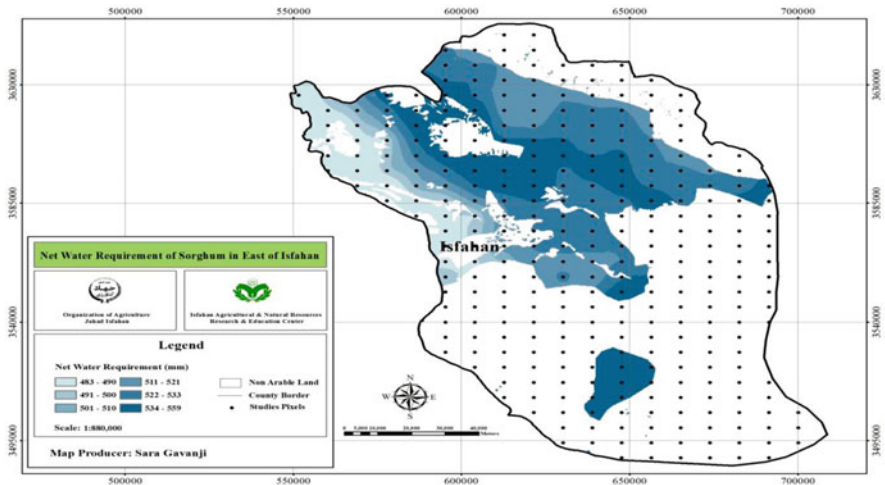
**Fig. 16.7** Range of irrigation requirements of wheat (Max–Min) in study area (simulation period 1978–2017)



**Fig. 16.8** Range of irrigation requirements of barley (Max–Min) in study area (simulation period 1978–2017)



**Fig. 16.9** Range of irrigation requirements of silage maize (Max–Min) in study area (simulation period 1978–2017)



**Fig. 16.10** Range of irrigation requirements of sorghum (Max–Min) in study area (simulation period 1978–2017)



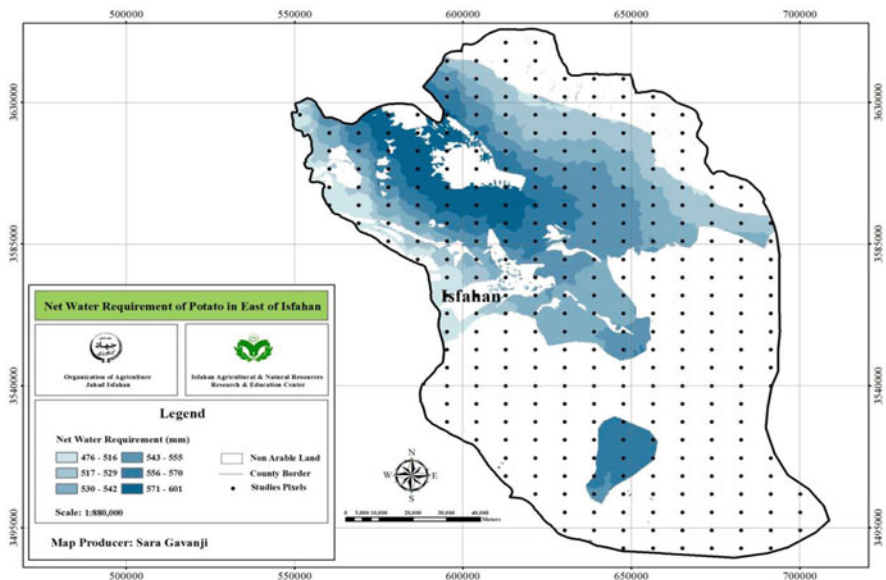


Fig. 16.11 Range of irrigation requirements of potato (Max–Min) in study area (simulation period 1978–2017)

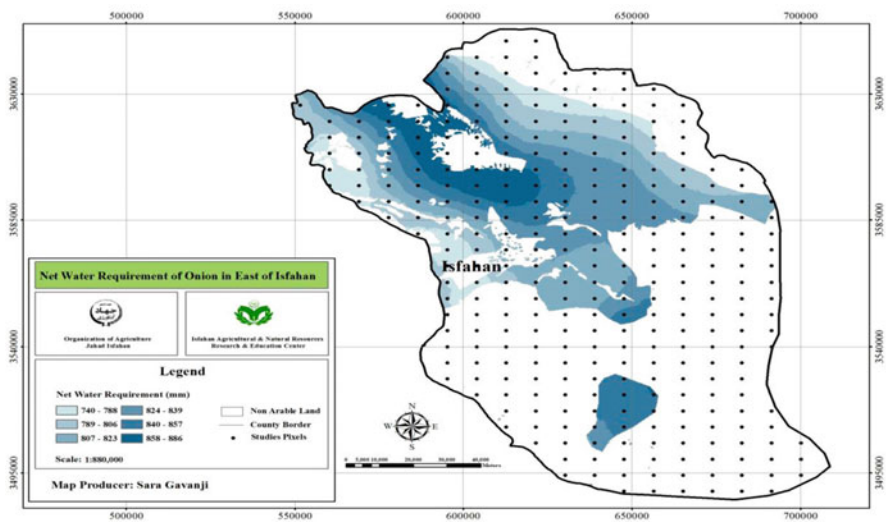
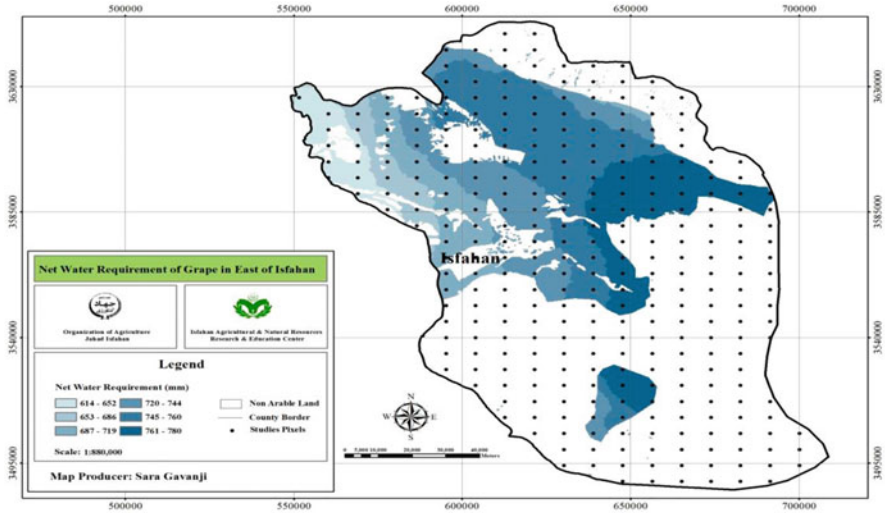
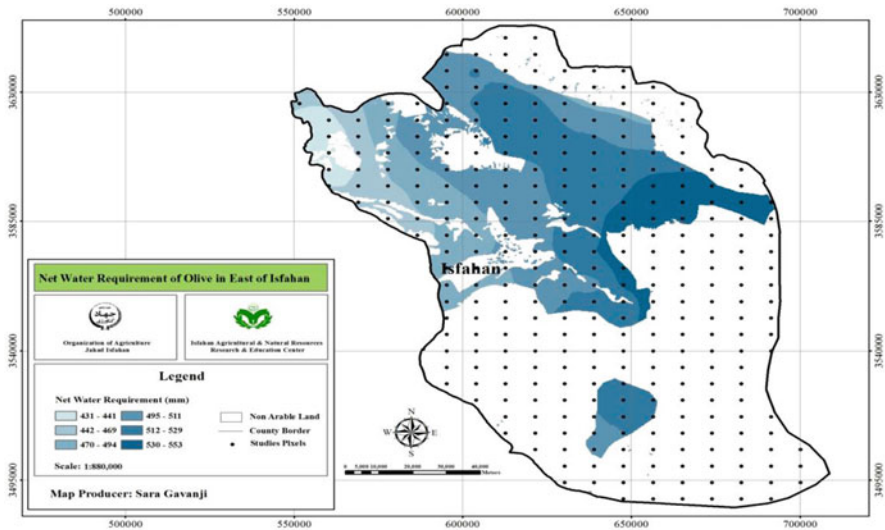


Fig. 16.12 Range of irrigation requirements of onion (Max–Min) in study area (simulation period 1978–2017)



**Fig. 16.13** Range of irrigation requirements of grape (Max–Min) in study area (simulation period 1978–2017)



**Fig. 16.14** Range of irrigation requirements of olive (Max–Min) in study area (simulation period 1978–2017)

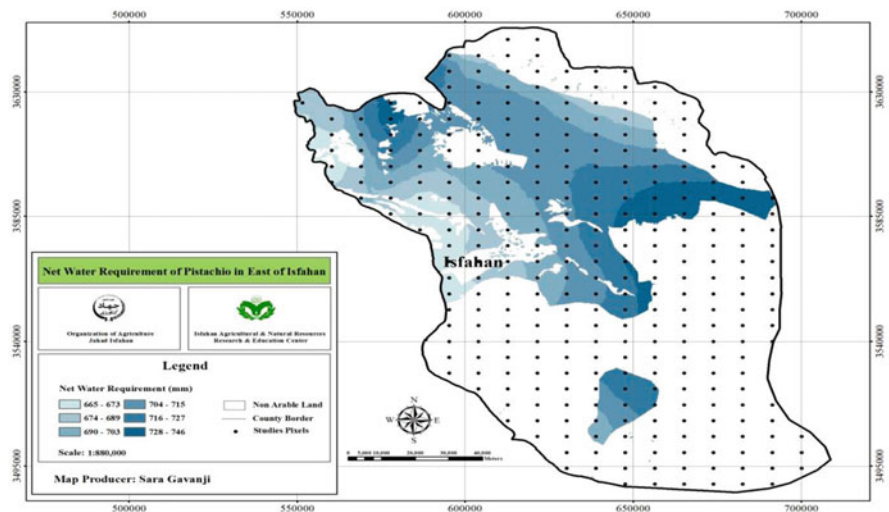


Fig. 16.15 Range of irrigation requirements of pistachio (Max–Min) in study area (simulation period 1978–2017)

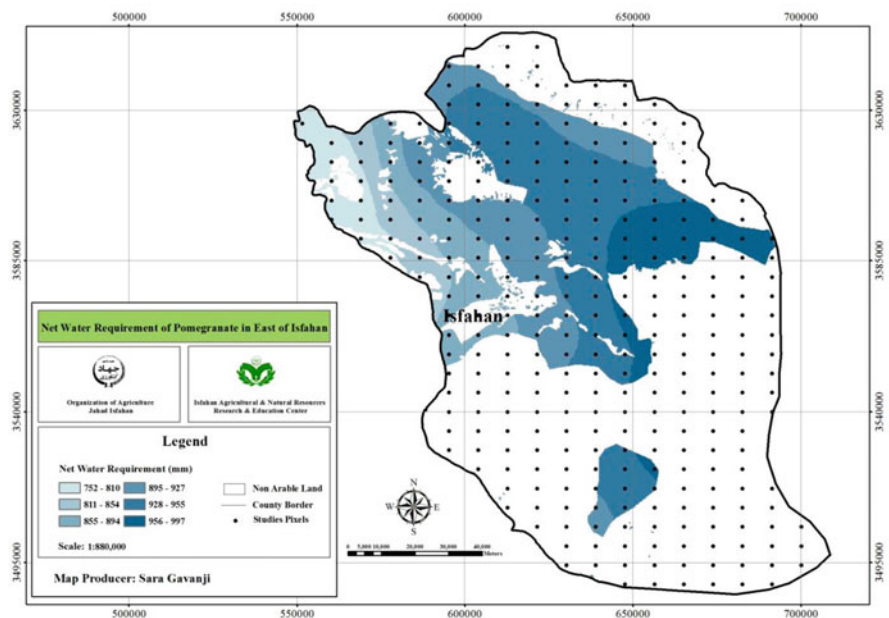


Fig. 16.16 Range of irrigation requirements of pomegranate (Max–Min) in study area (simulation period 1978–2017)

## 16.4 Conclusion

To meet Iranian food demand, the volume of water allocated to agriculture will have to increase, and by the year 2021 it will exceed 150 BCM, which is 15% in excess of the country's total potential renewable freshwater resources (Alizadeh 2005). Given that Iran is currently using 66% of its freshwater resources for irrigation as compared to a world average of 45% (Mousavi 2005), this increase would be impossible to meet. Irrigation efficiency and water productivity may be increased in the ZRB based on estimates of ETo from the NWR model, by meting the water demand accurately. According to the graph outputs of the ETo amounts, annual reference evapotranspiration varied between 1219 mm in the western region of the province to over 2027 mm in the eastern parts of Isfahan province. It can be concluded that the eastern parts of the ZRB (Isfahan city), which had low amounts of annual rainfall and high annual ETo, are often confronted with water deficits. Crop water requirement in this study refers to the accumulated crop evapotranspiration over the growing period for a certain crop group. Net irrigation requirements estimated by the NWR model are useful for providing balanced estimates on the ZRB's scale. There is a need to assess serious technical irrigation issues in the study area when conflicts between water supply and demand in multiple cropping irrigation schemes arise. In this way, gross irrigation requirements will be estimated at regional level considering the efficiency of irrigation methods as future studies.

**Acknowledgments** The present study was funded by the *Jihad-e-Agriculture Organization* of the Isfahan Province. The support of the Isfahan Agricultural and Natural Resources Research and Education Center (Project 34 - 38 - 14030930 - 94126) is also acknowledged.

## References

- Alizadeh A (2005) Status of agricultural water use in Iran. In: Proceedings of an Iranian-American workshop on water conservation, reuse and recycling, Tunis, Tunisia, Dec. 11–13. National Academies Press, Washington, DC, pp 94–105
- Alizadeh A, Kamali GhA (2007) Crop water requirement in Iran. Astan Ghods Razavi press. Imam Reza (A) U (in Farsi)
- Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration Guidelines for computing crop water requirements. Irrigation and Drainage. Paper 56. FAO, Rome, Italy, p 300
- Anonymous (1993) Comprehensive studies for agriculture development of the Zayandeh Rud basin, environment. Yekom Consulting Engineers, Water Resources, vol 25. Ministry of Agriculture, Iran
- Anonymous (1998) Detailed soil survey and land classification of Oushian area (Isfahan). Ministry of Agriculture and Natural Resources Soil Institute of Iran, pub. no. 396
- Anonymous (2005) Isfahan water authority. Policy Framework for Water in Agriculture
- Araya A, Habtub S, MelesHadguc K, Kebedea A, Dejene T (2010) Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley. Agric Water Manag 97:1838–1846

- Bastiaanssen WGM, Allen RG, Droogers P, D'Urso G, Steduto P (2007) Review: twenty-five years modeling irrigated and drained soils: state of the art. *Agric Manag* 92:111–125. <https://doi.org/10.1016/j.agwat.2007.05.013>
- Bodner G, Nakhforoosh A, Kaul HP (2015) Management of crop water under drought: a review. *Agron Sustain Dev* 35:401–442
- Chen C, Wang EY, Yu Q (2010) Modelling the effects of climate variability and water management on crop water productivity and water balance in the North China Plain. *Agric Water Manag* 97 (8):1175–1184
- DehghaniSanija H, Yamamoto T, Rasiahb V (2004) Assessment of evapotranspiration estimation models for use in semi-arid environments. *Agric Water Manag* 64:91–106
- Droogers P, Torabi M (2002) Field scale scenarios for water and salinity management by simulation models, Isfahan province, Iran, Research Report No.12. Iranian Agriculture Engineering Research Institute and IWMI
- Farshi AA (1997) Estimating required water of country's main plants of farming and gardening. Farming Education Press (in Farsi)
- Ghaffari A, Ghasemi VR, De Pauw E (2015) Agro-climatically zoning of Iran by UNESCO approach. *Iranian Dryland Agric J* 1–4:63–95
- Gohari A, Eslamian S, Abedi-Koupaei J, Bavani AM, Wang D, Madani K (2013) Climate change impacts on crop production in Iran's Zayandeh-Rud River Basin. *Sci Total Environ* 442:405–419
- Heng LK, Hsiao T, Evett S, Howell T, Steduto P (2009) Validating the FAO AquaCrop model for irrigated and water deficient field maize. *Agron J* 101:487–498
- Herms DA (2004) Using degree-days and plant phenology to predict pest activity. IPM (integrated pest management) of Midwest landscapes, pp 49–59
- Hillel D (1980) *Fundamentals of soil physics*. Academic, New York
- Jafaraghaei M, Dehghani M (2010) Study of irrigation management effect on qualitative and quantities characteristic in two cotton varieties in Esfahan. Isfahan Agricultural and Natural Resources Research Center. Ministry of Jihad-e-Agriculture. Final research report. No: 3-03-18160000-0000-84002. 25 pages (In Persian)
- Jalali A, Salemi HR, Nikouei A, Gavangy S, Rezaei M, Khodaghali M, Toomanian N (2017) Determination of water requirement for potato in different climates of Isfahan province. *Appl Res Field Crops* 3–4:53–76
- Keshavarz A, Ashrafi Sh, Hydari N, Pouran M, Farzaneh E (2005) Water allocation and pricing in agriculture of Iran. In: Proceeding of an Iranian-American workshop on water conservation, reuse and recycling, Tunis, Tunisia, Dec. 11–13. National Academies Press, Washington, DC, pp 153–172
- Keshavarz M, Karami E, Kamkare-Haghighi A (2010) A typology of farmers' drought management. *American-Eurasian J. Agric Environ Sci* 7(4):415–426
- Keshavarz M, Karami E (2012) The impact of human capital on agricultural development of drought-prone areas. In: The 8th biennial conference of Iranian Agricultural Economics Society, 9–10 May 2012, Shiraz, Iran
- Khaleghi N (2016) Comparison of effective rainfall estimation methods in agriculture. *J Water Sustain Dev* 2:51–58
- Kuo SF, Ho SS, Wuing Liu C (2006) Estimation irrigation water requirements with derived crop coefficients for upland and paddy crops in ChiaNan Irrigation Association, Taiwan. *Agric Water Manag* 82:433–451
- Llorens L, Penuelas J (2005) Experimental evidence of future drier and warmer conditions affecting flowering of two co-occurring Mediterranean shrubs. *Int J Plant Sci* 166:235–245
- Mahluji M, Mamanpush AR, Jafari A (2006) Deficit irrigation application in new barley genotypes. *Agric Sci Res J* 16(3):23–32
- Maton L, Leenhardt D, Goulard M, Bergez J-E (2005) Assessing the irrigation strategies over a wide geographical area from structural data about farming systems. *Agric Syst* 86:293–311. <https://doi.org/10.1016/j.agry.2004.09.010>

- Menzel A, Sparks TH, Estrella N, Koch E, Aasa A, Ahas R, Alm-Kübler K, Bissolli P, Braslavská OG, Briede A, Chmielewski FM (2006) European phenological response to climate change matches the warming pattern. *Global Change Biol* 12:1969–1976
- Mostafazadeh-Fard B, Heidarpour M, Hashemi SB (2009) Species factor and evapotranspiration for an ash and cypress in an arid region. *Aust J Crop Sci* 3(2):71–82
- Mousavi SF (2005) Agricultural drought management in Iran. In: Proceedings of an Iranian-American workshop on water conservation, reuse and recycling, Tunis, Tunisia, Dec. 11–13. National Academies Press, Washington, DC, pp 106–113
- OCHA. Office for the Coordination of Humanitarian Affairs (2001) Iran—drought OCHA situation report no. 1 (Ref: OCHA/GVA2001/0135). <http://reliefweb.int/node/83752>. Accessed 9 Aug 2011
- Ramazani-Etedali H, Nazari B, Tavakoli A, Parsinejad M (2009) Evaluation of CROPWAT model in deficit irrigation management of wheat and barley in Karaj. *J Water Soil* 23(1):119–129
- Roshan GR, Grab SW (2012) Regional climate change scenarios and their impacts on water requirements for wheat production in Iran. *Int J Plant Prod* 6:239–266
- Salemi HR (2012) Cropping pattern optimization for water resources allocation in an arid region, central Iran. Ph.D. thesis, UPM University, p 320
- Salemi HR (2013) Assessment of water and energy productivity in onion planting using drip tape irrigation in silty loam soil. Research Final Report 1–52 (in Persian, abstracted in English)
- Salemi HR, Afyuni D (2005) The effect of deficit irrigation on grain yield and yield components of new wheat cultivars. *Sci Nat Resour* 3(12):11–20 (in Persian, abstracted in English)
- Salemi HR, Amin MSM, Lee TS, Yusoff MK (2011) Impact of water resources availability on agricultural sustainability in the Gavkhuni River Basin, Iran. *J Sci Technol (JST) Pertanika J Trop Agric Sci* 34(2):207–216
- Salemi HR, Torabi M, Heidarisoltanabadi M (2017) Effects of deficit irrigation on quality indices and yield of maize in Isfahan region. Isfahan Agricultural Research Center (EARC), Iran. Annual Research Final Report 1–38 (In Persian, abstracted in English)
- Tao F, Zhang Z (2010) Adaptation of maize production to climate change in North China Plain: quantify the relative contributions of adaptation options. *Eur J Agron* 33:103–116
- Toda O, Yoshida K, Hiroaki S, Katsuhiko H, Tanji H (2005) Estimation of irrigation water using Cropwat model at KM34 project site, in Savannakhet, LAO PDR. (PP 17-24). Role of Water Sciences in Transboundary River Basin Management, Thailand
- Todorovic M, Albrizio R, Zivotic L, Abi Saab MT, Stöckle C, Steduto P (2009) Assessment of AquaCrop, CropSyst, and WOFOST models in the simulation of sunflower growth under different water regimes. *Agron J* 101:508–521
- Toomanian N (2016) Isfahan Aggr. and Natural Resources Research Center, Soil and Water Research Division, Laboratory Analysis (unpublished data)
- Weatherhead EK, Knox JW (2000) Predicting and mapping the future demand for irrigation water in England and Wales. *Agric Water Manag* 43:203–218
- Wriedt G, Van der Velde M, Aloe A, Bouraoui F (2009) Estimating irrigation water requirements in Europe. *J Hydrol* 373:527–544