

# Role of early warning systems for sustainable agriculture in Iran

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Received: 24 November 2015 / Accepted: 7 September 2016 / Published online: 26 November 2016  
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**Abstract** Drought is a complex phenomenon in meteorology and can affect agriculture. Its impacts vary greatly since they depend not only on the magnitude, timing, duration, and frequency of rainfall deficits but also on the differing responses of various plants to water stress. The essence of good drought management is to use this range of responses to the best advantage. Iran is one of the world's largest and most productive suppliers of food and fiber. The objective of this study was, therefore, to gather and analyze standardized information on the Role of Early Warning Systems for Sustainable Agriculture for cereals and leguminous and industrial crops in Iran environmental zones. Annual average rainfall ( $\text{mm year}^{-1}$ ) and  $\text{ET}_0$  ( $\text{mm year}^{-1}$ ) are 76.56 and 3001, respectively, in stations with very dry climate; 195.41 and 2249, respectively, in stations with dry climate; 343.9 and 1351, respectively, in stations with semi-dry climate; 583.8 and 1153, respectively, in stations with semi-humid climate; and 1272 and 949, respectively, in stations with humid climate. The maximum and minimum of annual average rainfall happened in Rasht ( $1337 \text{ mm year}^{-1}$ ) and Zabol ( $57 \text{ mm year}^{-1}$ ) stations, and the maximum and minimum for annual average  $\text{ET}_0$  happened in Chabahar ( $3909.15 \text{ mm year}^{-1}$ ) and Anzali harbor ( $890.6 \text{ mm year}^{-1}$ ), respectively. Therefore, 13.63 % of stations have suitable conditions for crop productions and 86.37 % are in critical conditions.

**Keywords** Evapotranspiration · Drought monitoring · Aridity index · Iran

## Introduction

Drought can only be considered as a relative phenomenon which originates from precipitation deficiency and occurs in high as well as low rainfall areas. Although droughts are still largely unpredictable, they are a recurring feature of the climate. Drought varies with regard to the time of occurrence, duration, intensity, and extent of the area affected from year to year. Each country needs to determine the collection of climate informations for sustainable agriculture. Therefore, decision makers can draw the future of their country in whole level. In agriculture sector, they need to get informations about evapotranspiration rates, drought (determination of aridity index), and choice for crops for each region (ecologic agriculture). In the future, many countries are likely to see negative impacts on subsistence agriculture due to the effects of global warming: increased temperatures and enhanced evapotranspiration, without offsetting precipitation increases. Increased climate variability is forecast, with more frequent extreme events (IPCC 2001). Creative strategies will be needed to adapt agricultural systems to changing conditions. Unfortunately, scientists in the affected countries often lack the necessary resources to fully utilize available technology for characterization of the climate situation. A program of investment in capacity building for climate science applications is needed to ensure that national policy makers have the basic climate information needed for decision making.

Also, the components of the early warning system are in ideal case (Monnik 2000): meteorological information, agricultural information, production estimates, price trends of food and feed, availability of drinking water, and household

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vulnerability. All these informations, supplemented with the possible forecast information, must be integrated to provide decision makers. This activity requests a great coordinating work, because as usual, there are many different services and institutes participate in the monitoring part of the process. The particular information deliverers are the owner of the information; they have to be compensated for the use of information, but from the other side, they are responsible for operating their network and quality of data. An important point of the early warning system (EWS) system is the education process, which is often forgotten. Education is very relevant, even at the best collaboration between the information provider and users. The users have to learn how to use distributed information.

Most of the farming systems currently located in hot and dry areas are expected to be most severely affected by climate change (Reilly and Schimmelpfennig 1999; Darwin and Kennedy 2000). There is a large variation across the European continent in climatic conditions, soils, land use, infrastructure, and political and economic conditions (Bouma et al. 1998). These differences are expected also to greatly influence the responsiveness to climate change (Olesen and Bindi 2002). Conventional hydrometeorological networks are sparse and often report with significant delays (Washington et al. 2004). Consequently, the requirements of famine early warning have inspired creative uses of remote sensing, numerical modeling, and geographic information systems (GIS) to adapt traditional methods of climate monitoring.

Drought can be monitored through the application of various statistical techniques. This requires the availability of long-term series of historical data as reference. Since the affected areas can be very different, several drought definitions have been developed and applied, which can be grouped in the following types: meteorological, hydrological, agricultural, and socioeconomic. Since no single index is adequate to evaluate the combined effects of meteorological, agricultural, and/or hydrological droughts, a variety of indices should be used. Meteorological drought is expressed solely on the basis of dryness or precipitation deficiency. The other definitions are more concerned with the effects on water flows, agriculture or economy, and society; reflecting the fact that impacts of drought are not limited on agricultural production, other sectors of economy like water management systems, transport, and industry can be affected as well. The main task of the monitoring and early warning systems is to provide timely information on the formation, development, and persistence of drought to the users and decision makers. The system collects, analyzes, and disseminates drought information. The new measurement instruments based on the latest technology can conduct observations rather frequently;

these time steps of measurements are shorter than it is necessary for drought monitoring. Therefore, drought does not require monitoring in small time steps. For instance, the EWS, an activity of the United States Agency for International Development (USAID), employs a livelihood framework to geographically characterize vulnerability and interpret hazards (Save the Children-UK 2000). Livelihood analysis focuses primarily on questions of access. Therefore, we have to investigate the prediction, monitoring, and early warning systems together. Based on the prediction and monitoring systems, the EWS allows for the early detection of drought conditions. It enables us to respond in a proactive rather than reactive manner.

There are 11 climates in Iran (13 climates in the world), 300 sunny days in year, and temperature difference from 40 to 50 °C in warmth and cool points in the country; opportunity conditions were being supplied for crop growth (Sharafi and Gholami 2010). Iran is one of the world's largest and most productive suppliers of food and fiber. In 2011, it accounted just 2.89 % of global crop productions. Unfortunately, 35 % of production decreased in 2014 (FAO 2014). Only 12 % of the total land area is under cultivation (arable land, orchards, and vineyards), but less than one third of the cultivated area is irrigated; the rest is devoted to dry farming. Some 92 % of agroproducts depend on water (Anonymous 2013). Iran's food security index stands at around 96 %. Thirty-five percent of the total land area is used for grazing and small fodder production. Most of the grazing is done on mostly semi-dry rangeland in mountain areas and on areas surrounding the large deserts of Central Iran (IMA 1995, 2012).

Therefore, the objective of this study was to gather and analyze standardized information on the Role of Early Warning Systems for Sustainable Agriculture for cereals and leguminous and industrial crops in Iran environmental zones.

## Material and methods

There are more than 200 synoptic stations in Iran, but 44 stations have long-term data (1951–2010). Then, we selected a similar duration for all stations from 1980 to 2010. For each climate division, monthly station climate data are computed from the daily observations. The divisional values are weighted by area to compute statewide values, and the statewide values are weighted by area to compute regional values. To gather information on perceived risks and foreseen impacts of climatic factors on crop production, we designed a set of qualitative and quantitative data from agrometeorological and agriculture organizations in 44 stations in Iran. It was assumed that both the crop production limitations and the

climate change are present within climatically homogenous zones. As a consequence, there should be marked differences between individual zones. To do so, the environmental zones were recently defined by Metzger et al. (2005) and Jongman et al. (2006).

Time series analysis is used to detect and describe quantitatively all generating processes underlying a given sequence of observations (Shahin et al. 1993) and is used for developing mathematical models to detect trends and shifts in meteorological and hydrological records and to fill in missing data and extend records (Salas 1993). A time series is often adequately described as a function of three components: trend, seasonality, and randomness. In general, the time series expression for meteorological studies is given as

$$x_t = T_t + S_t + \varepsilon_t + \eta_t \tag{1}$$

where  $T_t$  is the trend component,  $S_t$  is the seasonality,  $\varepsilon_t$  is the dependent stochastic component, and  $\eta_t$  is the independent residual component. Therefore, we used two methods for analyzing our data. The critical values for the Mann-Kendall test were obtained from Salas (1993). It is apparent that the differences between the observed and expected numbers of individual phases for Kendall’s phase lengths test are small for the annual temperature time series, whereas they are significant for all maximum temperature series. These indicate the absence of trend in the annual temperature time series and the presence of trend in all the maximum temperature time series.

Another method is exact, and it is the method of least squares (MLS). The method of least squares was introduced by Gauss (1777–1855). Given the observations  $X = (X_1, X_2, \dots, X_n)$  and  $Y = (Y_1, Y_2, \dots, Y_n)$ , a regression model can be fitted. For the general case

$$E(Y/X) = \alpha + \beta x \tag{2}$$

With  $\sigma^2$  as the assumed constant variance of  $Y$  around its regression line, the parameter estimates are

$$\begin{aligned} \alpha^* &= m_Y - \beta^* m_X \\ \beta^* &= S_{XY} / S_X^2 \\ \sigma^{2*} &= n / (n - 2) (1 - r_{XY}^2) s_Y^2 \end{aligned} \tag{3}$$

In which  $m_X, m_Y, S_X, S_Y, S_{XY}$  and  $r_{XY}$  are defined as

$$\begin{aligned} m_X &= 1/n \sum_{i=1, \dots, n} x_i \\ m_Y &= 1/n \sum_{i=1, \dots, n} Y_i \\ s_X^2 &= 1/n \sum_{i=1, \dots, n} (X_i - m_X)^2 \\ s_Y^2 &= 1/n \sum_{i=1, \dots, n} (Y_i - m_Y)^2 \\ s_{XY} &= 1/n \sum_{i=1, \dots, n} (X_i - m_X)(Y_i - m_Y) \\ r_{XY} &= s_{XY} / s_X s_Y \end{aligned} \tag{4}$$

The estimators  $\alpha^*$  and  $\beta^*$  are linear functions of  $Y_i$  and  $s$ , and they are unbiased. Their variances are

$$\begin{aligned} \sigma_A^2 &= \sigma^2 / n (1 + m_x^2 / s_X^2) \\ \sigma_B^2 &= \sigma^2 / n s_X^2 \end{aligned} \tag{5}$$

where A and B are respectively  $\alpha^*$  and  $\beta^*$  treated as random variables. With the above regression techniques, the MLS can be defined. Assume that  $n$  observations are in a sorted order given by  $X_{1:n}, X_{2:n}, \dots, X_{n:n}$  and define the plotting position  $p_i = i / (n + 1)$  of the  $i$ th observation. Therefore, we want to estimate the optimal value  $\theta$  of the distribution function  $F(X/\theta)$  in least square sense (Demetracopoulos 1994). In general, we have 5 stations (11.32 % of total stations) with very dry climate, 21 stations (47.72 %) with dry climate, 13 stations (29.54 %) with semi-dry climate, and 5 stations (11.32 %) with humid climate. To calculate the long-term annual average data, for example, the average temperature of the first month of the monthly average of the minimum and maximum temperatures and the averaged annual mean temperature of the monthly temperature were measured for each of the stations studied. In order to calculate the first-year annual average temperature data in one column and the other columns in Excel 2012 arrived, the slope and intercept of the line were obtained by the method of least squares and the error was determined. Also, in order to test the significance of the slope of the line at zero, or test, the  $t$  statistic was calculated from the following equation:

$$t = \frac{b}{s_b} \tag{6}$$

A test of the significance of differences in slope or zero is done in three steps as follows: (1) the total length, which is the length of the year in which the desired station is hit until the end of the period (1980–2010); (2) the period of common, in which the same attitude to the process of annual mean data at each station for a period of joint is selected and which is the longest period that would be shared by all the stations that have data from 1980 to 2010 and would be elected; and (3) the statistical sequential order to investigate how changes in the annual mean data in successive statistical periods, from the outset, and in order to remove any of the years during the subsequent process steps and shorter length was calculated. The shortest period of 5 years was considered.

Potential evapotranspiration or  $ET_O$  is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration, assuming no control on water supply. Actual evapotranspiration or AE is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. Scientists consider these two types of evapotranspiration for the practical purpose of water resource management. Around

the world, humans are involved in the production of a variety of crops. Many of these crops grow in environments that are naturally short of water. As a result, irrigation is used to supplement the crop's water needs. Managers of these crops can determine how much supplemental water is needed to achieve maximum productivity by estimating potential and actual evapotranspiration (Allen et al. 1998; Doorenbos and Pruitt 1977; Penman 1956). Based on observations, there are five climates in Iran. For each station selected, a special formula and calculated  $R^2$ , Root Mean Square Error (RMSE) ( $\text{mm day}^{-1}$ ), and Mean Bias Error (MBE) ( $\text{mm day}^{-1}$ ) were used for selected and suggested models (Table 1).

Empirical crop coefficients ( $K_C$  from FAO<sub>56</sub> report) are used to relate the reference crop evapotranspiration to crop evapotranspiration under non-standard conditions (Allen et al. 1998) (Table 2). The use of computer models in agriculture to simulate evapotranspiration is widespread. Most of the models are currently used on an operational basis in global scale. Direct and indirect methods of measuring evapotranspiration, which are costly and time consuming, are reviewed in detail by Brutsaert (1982). However, estimates of evapotranspiration based on readily available ecological climate data are possible by employing the concept of evapotranspiration. This concept is widely accepted and was first proposed by Thornthwaite (1944, 1948). It has, however, become a common practice to use the terms potential evaporation and potential evapotranspiration interchangeably in the literature despite their different definitions in terms (Priestley and Taylor 1972; Jensen et al. 1990; Maidment 1992) (Table 1). The multiplication of  $ET_O$  values in  $K_C$  for initial, middle, and end of crop growth stages (wheat, barley, corn, rice, bean, chickpea, lentil, alfalfa, sunflower, soybean, canola, sugar beet, potato, and cotton) gives  $ET_C$ . The maximum water demand for specific crop is estimated by

$$ET_C = K_C \times ET_O \quad (7)$$

where  $ET$  is the specific crop evapotranspiration and  $K_C$  is the crop coefficient, a coefficient expressing the difference in evapotranspiration between the crop and reference grass surface. The average crop coefficient ( $K_C$ ) values for spring wheat under different growing stages have been suggested by FAO<sub>56</sub> reports (Table 2).

Several methods exist for drought prediction, but the obvious way is to calculate drought monitoring elements from the seasonal forecast. Unfortunately, this method is yet not in practice in our country. It is well known that the skills of the seasonal forecast are rather divergent in different regions in the world. Also, according to Wilhite and Svoboda (2000), there are the primary tasks for the monitoring processes, for example to adopt an applicable definition for grading of drought. Many drought indices exist in consequence of drought definition multiplicity. Therefore, it is important to evaluate the performance of several drought indices in drought situation, for which comparative case studies can be accomplished. The evaluation includes the index potential for use in early warning conditions and identifying the different effects of drought on hydrological features, groundwater table, yield, and state economy.

The collaborative historical rainfall model (Funk et al. 2003) was developed and applied to create a many-year time series of daily rainfall grids. We used the aridity index (based on two methods: FAO<sub>56</sub> and UNESCO) to obtain monthly station data (Willmott and Feddema 1994; Willmott and Matura 1995; Kalnay 1996). In this study, we used the daily values of 60-year long time series (1951–2010) at 44 stations in Iran climatic conditions, because it was the longest common part of different series. For the comparison of two indices, we used the simple correlation coefficient with no lag, and 1, 2, etc., months of lag (Szalai et al. 2000). On the other hand, the objective was to create a time-series product with submonthly variability, constrained to match monthly station totals.

**Table 1** The estimated error of  $ET_O$  by the used models for Iran climatic conditions

Climate	$R^2$	RMSE ( $\text{mm day}^{-1}$ )	MBE ( $\text{mm day}^{-1}$ )	Selected model	Suggested models
Semi-humid	0.86	0.83	0.12	HgS <sub>1985</sub>	$ET_{O \text{ Hgs}} = 0.0162(k_r) \cdot R_A \cdot TD^{0.5}(T + 17.8)$
	0.62	1.20	0.06	HgS <sub>1985</sub>	
Dry	0.85	0.85	-0.51	Pen <sub>1948</sub>	$ET_{O \text{ Pen1948}} = \frac{\Delta R_{n+\gamma} E_a}{\Delta + \gamma}$
	0.87	1.24	-0.84	Pen <sub>1948</sub>	
Humid	0.76	0.42	0.06	Pen <sub>F24</sub>	$ET_{O \text{ PenF24}} = C \left[ \frac{\Delta}{\Delta + \gamma} R_n + \frac{\gamma}{\Delta + \gamma} (0.27) (1 + 0.01 U_{2m}) (e_{sa} - e_a) \right]$
Very dry	0.93	1.43	-0.41	PMF <sub>56</sub>	$ET_{O \text{ PMF56}} = \frac{0.48(R_n - G) + \gamma \frac{900}{T + 237} U_2 (e_{sa} - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}$
	0.88	2.45	-0.87	PMF <sub>56</sub>	
Semi-dry	0.96	0.09	-0.66	BC <sub>24</sub>	$ET_{O \text{ BC24}} = a + b(p(0.46T + 8.13))$
	0.91	1.35	0.97	BC <sub>24</sub>	
Average	0.85	1.1	-0.23	-	-

**Table 2** Average crop coefficients and maximum crop height (m) under condition without stress and with optimum agriculture management ( $RH_{min} = 45$ , wind velocity =  $2 \text{ m s}^{-1}$ )

Crop	$K_{Cini}$	$K_{Cmid}$	$K_{Cend}$	Maximum crop height (m)
Wheat	0.40	1.15	0.25–0.40	1.00
Barley	0.30	1.15	0.25	1.00
Corn	0.70	1.20	0.35–0.60	2.00
Rice	1.05	1.20	0.60–0.90	1.00
Bean	0.40	1.15	0.35	0.40
Chickpea	0.40	1.15	0.35	0.40
Lentil	0.40	1.10	0.30	0.50
Alfalfa	0.40	0.95	0.90	0.70
Sunflower	0.35	1.00–1.15	0.35	2.00
Soybean	0.40	1.15	0.50	0.50–1.00
Canola	0.35	1.10–1.50	0.35	0.60
Sugar beet	0.35	1.20	0.70	0.50
Potato	0.50	1.15	0.75	0.60
Cotton	0.35	1.15–1.20	0.50–0.70	1.20–1.50

Validation with independent station data at areas showed good results in reproduction ( $r = 0.85$ ), but with significant bias in some stations (Table 2). The first method is based on the FAO<sub>56</sub> report (Table 3)

$$AI_{FAO56} = \frac{PE-AE}{PE} \times 100 \tag{8}$$

The second methods is  $AI_{UNESCO}$ , and this index (Table 4) is calculated by precipitation (P) and evapotranspiration potential ( $ET_O$ )

$$AI = \frac{P}{ET_O} \times 100 \tag{9}$$

### Results and discussions

In this article, we classified all stations based on  $ET_O$ ,  $ET_C$ , and precipitation values. Based on Figs. 1 and 3, west, north, and northwest regions of Iran have good conditions for selected crops, but in regions of south, southwest, and southeast because of high evapotranspiration and water shortage,

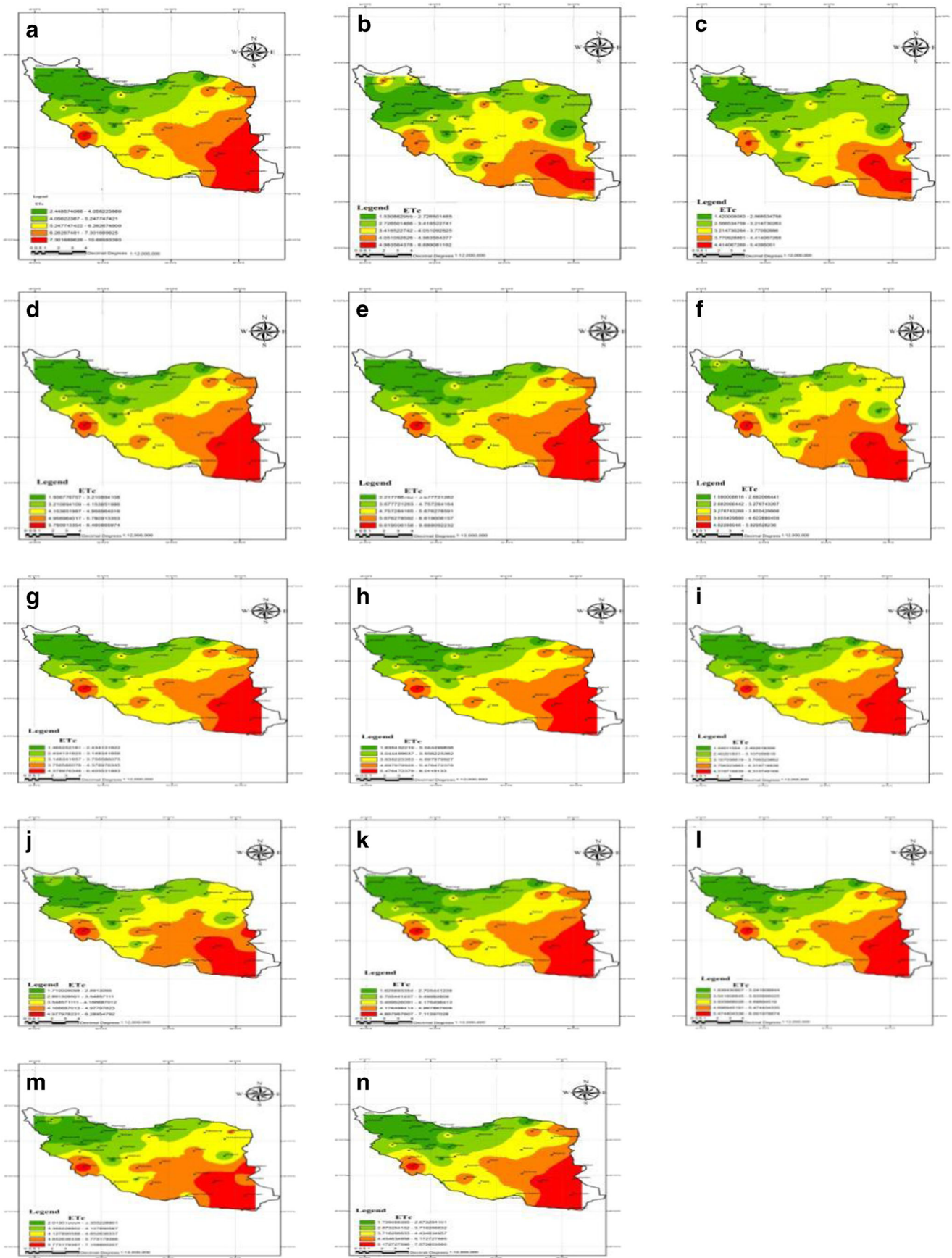
**Table 3** Aridity index ( $AI_{FAO56}$ ) based on climate data

Region	AI
Humid	Negative to 0
Semi-dry	1–25
Dry	26–50
Very dry	50

**Table 4** Aridity index ( $AI_{UNESCO}$ ) based on climate informations

Region	AI
Very dry	<0.03
Dry	0.03–0.2
Semi-dry	0.2–0.5
Semi-humid	0.5–0.75
Humid	0.75–1
Very humid	>1

agriculture is reduced and farmers cannot cultivate all crops and they have to select few crops, for instance special cultivars of wheat, barley and alfalfa, thus reducing agrobiodiversity. Finally, sustainable agriculture has been threatened by erosion, drought, and immigration of farmers to cities. Table 5 shows that wheat and barley have the same conditions, and farmers can cultivate them in all regions. The natural and climatic conditions for rice are inverted. Just a few regions are suitable for its cultivation (Anzali harbor, Rasht, Ramsar, Noshahr, and Gorgan stations). In the mentioned stations, there are 125 with cloudy sky, and therefore,  $ET_C$  rate is lower than  $3 \text{ mm day}^{-1}$ . Also, the results indicated that Tabriz, Ardabil, Khoy, Uromieh, and Zanjan stations are suitable for its cultivation, but the inhibitor factor is low temperature in these stations (Table 5, Fig. 1a–d). In relation to leguminous family and its cultivation ability in Iran climatic conditions, the results showed that Anzali harbor, Birjand, Ghazvin, Gorgan, Hamedan, Kermanshah, Ramsar, Rasht, Shiraz, Ardabil, Khoy, Sanandaj, Shahrekord, and Zanjan have good climatic conditions for cultivation of bean and chickpea (Table 6). Also, these conditions were provided for lentil and alfalfa, and the affecting factors are economically potential, because farmers select cash crops with maximum profitability (Table 6, Fig. 1g, h). Based on the results in Table 7, the maximum of  $ET_C$  for sunflower happened in the stations of Chabahar and Zabol ( $6.33$  and  $6.11 \text{ mm day}^{-1}$ ). For soybean, it was  $6.29$  and  $6.26 \text{ mm day}^{-1}$  respectively, which happened in Iranshahr and Bam stations. The maximum of  $ET_C$  for canola happened in the Zabol station ( $6.88 \text{ mm day}^{-1}$ ). The minimum of  $ET_C$  for sunflower, soybean, and canola happened in stations of Noshahr ( $1.48 \text{ mm day}^{-1}$ ), Ramsar ( $1.71 \text{ mm day}^{-1}$ ), and Zanjan ( $1.21 \text{ mm day}^{-1}$ ), respectively (Table 7, Fig. 1i–k). The climatic conditions of Noshahr and Ramsar stations are humid, in which mesophyte crops (e.g., sunflower and canola) can be cultivated, but for the Zanjan station, the condition is different. In this station, the weather is cold and the duration of cultivation season is short, and then the farmers have to cultivate a few crops that can tolerate cold conditions (e.g., canola, wheat, and barley). For sugar beet, the maximum of  $ET_C$  happened in the Chabahar station ( $8.03 \text{ mm day}^{-1}$ ). The  $ET_C$  values for potato happened in Bam and Iranshahr stations ( $7.16$  and  $7.14 \text{ mm day}^{-1}$ ). The maximum value of  $ET_C$  for cotton was in Chabahar and Zabol



◀ **Fig. 1** The maps of  $ET_O$  (a) and  $ET_C$  for wheat (b), barley (c), corn (d), rice (e), bean and chickpea (f), lentil (g), alfalfa (h), sunflower (i), soybean (j), canola (k), sugar beet (l), potato (m), and cotton (n) in Iran climatic conditions

stations (7.59 and 7.34 mm day<sup>-1</sup>). The minimum values of  $ET_C$  happened for three industrial crops: sugar beet (Anzali harbor, 1.83 mm day<sup>-1</sup>), potato (Ramsar, 2.01 mm day<sup>-1</sup>), and

**Table 5** Calculated  $ET_O$ , AE (for initial, middle, and end of crop growth stages), and  $ET_C$  rates for cereals

Station	$ET_O$	Wheat			Barley				Corn				Rice				
		$AE_{ini}$	$AE_{mid}$	$AE_{end}$	$ET_C$	$AE_{ini}$	$AE_{mid}$	$AE_{end}$	$ET_C$	$AE_{ini}$	$AE_{mid}$	$AE_{end}$	$ET_C$	$AE_{ini}$	$AE_{mid}$	$AE_{end}$	$ET_C$
Abadan	8.29	3.32	9.53	2.69	5.18	2.49	9.53	2.07	4.70	5.80	9.95	3.94	6.56	8.70	9.95	3.90	7.52
Ahwaz	8.05	3.22	9.26	2.62	5.03	2.42	9.26	2.01	4.56	5.64	9.66	3.82	6.37	8.45	9.66	3.78	7.30
Lengeh harbor	5.84	3.22	9.26	2.62	5.03	1.75	9.26	1.46	4.16	4.09	7.01	2.77	4.62	6.13	7.01	2.74	5.29
Abbas harbor	5.74	2.34	6.72	1.90	3.65	1.72	6.72	1.44	3.29	4.02	6.89	2.73	4.54	6.03	6.89	2.70	5.20
Bushehr	5.20	2.30	6.60	1.87	3.59	1.56	6.60	1.30	3.15	3.64	6.24	2.47	4.12	5.46	6.24	2.44	4.71
Chabahar	10.71	2.08	5.98	1.69	3.25	3.21	5.98	2.68	3.96	7.50	12.8	5.09	8.48	11.2	12.8	5.03	9.71
Iranshahr	7.30	4.28	12.3	3.48	6.69	2.19	12.3	1.83	5.44	5.11	8.76	3.47	5.78	7.67	8.76	3.43	6.62
Kerman	7.03	2.92	8.40	2.37	4.56	2.11	8.40	1.76	4.09	4.92	8.44	3.34	5.57	7.38	8.44	3.30	6.37
Tabas	5.74	2.81	8.08	2.28	4.39	1.72	8.08	1.44	3.75	4.02	6.89	2.73	4.54	6.03	6.89	2.70	5.20
Yazd	6.95	2.30	6.60	1.87	3.59	2.09	6.60	1.74	3.47	4.87	8.34	3.30	5.50	7.30	8.34	3.27	6.30
Zabol	10.34	2.78	7.99	2.26	4.34	3.10	7.99	2.59	4.56	7.24	12.4	4.91	8.19	10.9	12.4	4.86	9.37
Bam	7.65	4.14	11.9	3.36	6.46	2.30	11.9	1.91	5.37	5.36	9.18	3.63	6.06	8.03	9.18	3.60	6.94
Dezful	6.88	3.06	8.80	2.49	4.78	2.06	8.80	1.72	4.19	4.82	8.26	3.27	5.45	7.22	8.26	3.23	6.24
Fasa	5.80	2.75	7.91	2.24	4.30	1.74	7.91	1.45	3.70	4.06	6.96	2.76	4.59	6.09	6.96	2.73	5.26
Isfahan	5.75	2.32	6.67	1.89	3.63	1.73	6.67	1.44	3.28	4.03	6.90	2.73	4.55	6.04	6.90	2.70	5.21
Kashan	3.67	2.30	6.61	1.87	3.59	1.10	6.61	0.92	2.88	2.57	4.40	1.74	2.91	3.85	4.40	1.72	3.33
Sabzevar	6.99	1.47	4.22	1.19	2.29	2.10	4.22	1.75	2.69	4.89	8.39	3.32	5.53	7.34	8.39	3.29	6.34
Semnan	4.62	2.80	8.04	2.27	4.37	1.39	8.04	1.16	3.53	3.23	5.54	2.19	3.66	4.85	5.54	2.17	4.19
Shahrud	4.91	1.85	5.31	1.50	2.89	1.47	5.31	1.23	2.67	3.44	5.89	2.33	3.89	5.16	5.89	2.31	4.45
Torbathedarieh	5.45	1.96	5.65	1.60	3.07	1.64	5.65	1.36	2.88	3.82	6.54	2.59	4.31	5.72	6.54	2.56	4.94
Zahedan	7.51	2.18	6.27	1.77	3.41	2.25	6.27	1.88	3.47	5.26	9.01	3.57	5.95	7.89	9.01	3.53	6.81
Abadeh	5.75	3.00	8.64	2.44	4.69	1.73	8.64	1.44	3.93	4.03	6.90	2.73	4.55	6.04	6.90	2.70	5.21
Arak	3.59	2.30	6.61	1.87	3.59	1.08	6.61	0.90	2.86	2.51	4.31	1.71	2.84	3.77	4.31	1.69	3.25
Anzali harbor	2.44	1.44	4.13	1.17	2.24	0.73	4.13	0.61	1.82	1.71	2.93	1.16	1.93	2.56	2.93	1.15	2.21
Birjand	6.52	0.98	2.81	0.79	1.53	1.96	2.81	1.63	2.13	4.56	7.82	3.10	5.16	6.85	7.82	3.06	5.91
Bojnord	3.35	2.61	7.50	2.12	4.08	1.01	7.50	0.84	3.11	2.35	4.02	1.59	2.65	3.52	4.02	1.57	3.04
Ghazvin	3.69	1.34	3.85	1.09	2.09	1.11	3.85	0.92	1.96	2.58	4.43	1.75	2.92	3.87	4.43	1.73	3.35
Gorgan	3.16	1.48	4.24	1.20	2.31	0.95	4.24	0.79	1.99	2.21	3.79	1.50	2.50	3.32	3.79	1.49	2.87
Hamedan	3.62	1.26	3.63	1.03	1.98	1.09	3.63	0.91	1.87	2.53	4.34	1.72	2.87	3.80	4.34	1.70	3.28
Kermanshah	5.42	1.45	4.16	1.18	2.26	1.63	4.16	1.36	2.38	3.79	6.50	2.57	4.29	5.69	6.50	2.55	4.91
Khoramabad	5.38	2.17	6.23	1.76	3.39	1.61	6.23	1.35	3.06	3.77	6.46	2.56	4.26	5.65	6.46	2.53	4.88
Mashhad	6.91	2.15	6.19	1.75	3.36	2.07	6.19	1.73	3.33	4.84	8.29	3.28	5.47	7.26	8.29	3.25	6.27
Noshahr	2.50	2.76	7.95	2.25	4.32	0.75	7.95	0.63	3.11	1.75	3.00	1.19	1.98	2.63	3.00	1.18	2.27
Ramsar	2.51	1.00	2.88	0.81	1.56	0.75	2.88	0.63	1.42	1.76	3.01	1.19	1.99	2.64	3.01	1.18	2.28
Rasht	2.96	1.00	2.89	0.82	1.57	0.89	2.89	0.74	1.51	2.07	3.55	1.41	2.34	3.11	3.55	1.39	2.68
Shiraz	6.94	1.18	3.40	0.96	1.85	2.08	3.40	1.74	2.41	4.86	8.33	3.30	5.49	7.29	8.33	3.26	6.29
Tabriz	3.05	2.78	7.98	2.26	4.34	0.92	7.98	0.76	3.22	2.14	3.66	1.45	2.41	3.20	3.66	1.43	2.77
Tehran	6.04	1.22	3.51	0.99	1.91	1.81	3.51	1.51	2.28	4.23	7.25	2.87	4.78	6.34	7.25	2.84	5.48
Ardabil	2.76	2.42	6.95	1.96	3.78	0.83	6.95	0.69	2.82	1.93	3.31	1.31	2.19	2.90	3.31	1.30	2.50
Khoy	3.26	1.10	3.17	0.90	1.73	0.98	3.17	0.82	1.65	2.28	3.91	1.55	2.58	3.42	3.91	1.53	2.96
Sanandaj	3.84	1.30	3.75	1.06	2.04	1.15	3.75	0.96	1.95	2.69	4.61	1.82	3.04	4.03	4.61	1.80	3.48
Shahrekordeh	3.80	1.54	4.42	1.25	2.40	1.14	4.42	0.95	2.17	2.66	4.56	1.81	3.01	3.99	4.56	1.79	3.45
Uromieh	3.06	1.52	4.37	1.24	2.38	0.92	4.37	0.77	2.02	2.14	3.67	1.45	2.42	3.21	3.67	1.44	2.77
Zanjan	3.32	1.22	3.52	0.99	1.91	1.00	3.52	0.83	1.78	2.32	3.98	1.58	2.63	3.49	3.98	1.56	3.01

**Table 6** Calculated ET<sub>O</sub>, AE (for initial, middle, and end of crop growth stages), and ET<sub>C</sub> rates for leguminous crop

Station	ET <sub>O</sub>	Bean				Chickpea				Lentil				Alfalfa			
		AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>
Abadan	8.29	3.32	9.53	2.90	5.25	3.32	9.53	2.90	5.25	3.32	9.12	2.49	4.98	3.32	7.88	7.46	6.22
Ahwaz	8.05	3.22	9.26	2.82	5.10	3.22	9.26	2.82	5.10	3.22	8.86	2.42	4.83	3.22	7.65	7.25	6.04
Lengeh harbor	5.84	2.34	9.26	2.04	4.55	2.34	9.26	2.04	4.55	2.34	6.42	1.75	3.50	2.34	5.55	5.26	4.38
Abbas harbor	5.74	2.30	6.72	2.01	3.68	2.30	6.72	2.01	3.68	2.30	6.31	1.72	3.44	2.30	5.45	5.17	4.31
Bushehr	5.20	2.08	6.60	1.82	3.50	2.08	6.60	1.82	3.50	2.08	5.72	1.56	3.12	2.08	4.94	4.68	3.90
Chabahar	10.71	4.28	5.98	3.75	4.67	4.28	5.98	3.75	4.67	4.28	11.8	3.21	6.42	4.28	10.2	9.64	8.03
Iranshahr	7.30	2.92	12.3	2.56	5.93	2.92	12.3	2.56	5.93	2.92	8.03	2.19	4.38	2.92	6.94	6.57	5.48
Kerman	7.03	2.81	8.40	2.46	4.56	2.81	8.40	2.46	4.56	2.81	7.73	2.11	4.22	2.81	6.68	6.33	5.27
Tabas	5.74	2.30	8.08	2.01	4.13	2.30	8.08	2.01	4.13	2.30	6.31	1.72	3.44	2.30	5.45	5.17	4.31
Yazd	6.95	2.78	6.60	2.43	3.94	2.78	6.60	2.43	3.94	2.78	7.65	2.09	4.17	2.78	6.60	6.26	5.21
Zabol	10.34	4.14	7.99	3.62	5.25	4.14	7.99	3.62	5.25	4.14	114	3.10	6.20	4.14	9.82	9.31	7.76
Bam	7.65	3.06	11.9	2.68	5.88	3.06	11.9	2.68	5.88	3.06	8.42	2.30	4.59	3.06	7.27	6.89	5.74
Dezful	6.88	2.75	8.80	2.41	4.65	2.75	8.80	2.41	4.65	2.75	7.57	2.06	4.13	2.75	6.54	6.19	5.16
Fasa	5.80	2.32	7.91	2.03	4.09	2.32	7.91	2.03	4.09	2.32	6.38	1.74	3.48	2.32	5.51	5.22	4.35
Isfahan	5.75	2.30	6.67	2.01	3.66	2.30	6.67	2.01	3.66	2.30	6.33	1.73	3.45	2.30	5.46	5.18	4.31
Kashan	3.67	1.47	6.61	1.28	3.12	1.47	6.61	1.28	3.12	1.47	4.04	1.10	2.20	1.47	3.49	3.30	2.75
Sabzevar	6.99	2.80	4.22	2.45	3.16	2.80	4.22	2.45	3.16	2.80	7.69	2.10	4.20	2.80	6.64	6.29	5.24
Semnan	4.62	1.85	8.04	1.62	3.84	1.85	8.04	1.62	3.84	1.85	5.08	1.39	2.77	1.85	4.39	4.16	3.47
Shahrud	4.91	1.96	5.31	1.72	3.00	1.96	5.31	1.72	3.00	1.96	5.40	1.47	2.94	1.96	4.66	4.42	3.68
Torbatheidarieh	5.45	2.18	5.65	1.91	3.25	2.18	5.65	1.91	3.25	2.18	6.00	1.64	3.27	2.18	5.18	4.91	4.09
Zahedan	7.51	3.00	6.27	2.63	3.97	3.00	6.27	2.63	3.97	3.00	8.26	2.25	4.50	3.00	7.13	6.76	5.63
Abadeh	5.75	2.30	8.64	2.01	4.32	2.30	8.64	2.01	4.32	2.30	6.33	1.73	3.45	2.30	5.46	5.18	4.31
Arak	3.59	1.44	6.61	1.26	3.10	1.44	6.61	1.26	3.10	1.44	3.95	1.08	2.16	1.44	3.41	3.23	2.69
Anzali harbor	2.44	0.98	4.13	0.85	1.99	0.98	4.13	0.85	1.99	0.98	2.68	0.73	1.46	0.98	2.32	2.20	1.83
Birjand	6.52	2.61	2.81	2.28	2.57	2.61	2.81	2.28	2.57	2.61	7.17	1.96	3.91	2.61	6.19	5.87	4.89
Bojnord	3.35	1.34	7.50	1.17	3.34	1.34	7.50	1.17	3.34	1.34	3.69	1.01	2.01	1.34	3.18	3.02	2.51
Ghazvin	3.69	1.48	3.85	1.29	2.21	1.48	3.85	1.29	2.21	1.48	4.06	1.11	2.22	1.48	3.51	3.32	2.77
Gorgan	3.16	1.26	4.24	1.11	2.20	1.26	4.24	1.11	2.20	1.26	3.48	0.95	1.90	1.26	3.00	2.84	2.37
Hamedan	3.62	1.45	3.63	1.27	2.12	1.45	3.63	1.27	2.12	1.45	3.98	1.09	2.17	1.45	3.44	3.26	2.72
Kermanshah	5.42	2.17	4.16	1.90	2.74	2.17	4.16	1.90	2.74	2.17	5.96	1.63	3.25	2.17	5.15	4.88	4.07
Khoramabad	5.38	2.15	6.23	1.88	3.42	2.15	6.23	1.88	3.42	2.15	5.92	1.61	3.23	2.15	5.11	4.84	4.03
Mashhad	6.91	2.76	6.19	2.42	3.79	2.76	6.19	2.42	3.79	2.76	7.60	2.07	4.14	2.76	6.56	6.22	5.18
Noshahr	2.50	1.00	7.95	0.88	3.28	1.00	7.95	0.88	3.28	1.00	2.75	0.75	1.50	1.00	2.38	2.25	1.88
Ramsar	2.51	1.00	2.88	0.88	1.59	1.00	2.88	0.88	1.59	1.00	2.76	0.75	1.50	1.00	2.38	2.26	1.88
Rasht	2.96	1.18	2.89	1.04	1.70	1.18	2.89	1.04	1.70	1.18	3.26	0.89	1.78	1.18	2.81	2.66	2.22
Shiraz	6.94	2.78	3.40	2.43	2.87	2.78	3.40	2.43	2.87	2.78	7.63	2.08	4.16	2.78	6.59	6.25	5.21
Tabriz	3.05	1.22	7.98	1.07	3.42	1.22	7.98	1.07	3.42	1.22	3.36	0.92	1.83	1.22	2.90	2.75	2.29
Tehran	6.04	2.42	3.51	2.11	2.68	2.42	3.51	2.11	2.68	2.42	6.64	1.81	3.62	2.42	5.74	5.44	4.53
Ardabil	2.76	1.10	6.95	0.97	3.01	1.10	6.95	0.97	3.01	1.10	3.04	0.83	1.66	1.10	2.62	2.48	2.07
Khoy	3.26	1.30	3.17	1.14	1.87	1.30	3.17	1.14	1.87	1.30	3.59	0.98	1.96	1.30	3.10	2.93	2.44
Sanandaj	3.84	1.54	3.75	1.34	2.21	1.54	3.75	1.34	2.21	1.54	4.22	1.15	2.30	1.54	3.65	3.46	2.88
Shahreکرد	3.80	1.52	4.42	1.33	2.42	1.52	4.42	1.33	2.42	1.52	4.18	1.14	2.28	1.52	3.61	3.42	2.85
Uromieh	3.06	1.22	4.37	1.07	2.22	1.22	4.37	1.07	2.22	1.22	3.37	0.92	1.84	1.22	2.91	2.75	2.29
Zanjan	3.32	1.33	3.52	1.16	2.00	1.33	3.52	1.16	2.00	1.33	3.65	1.00	1.99	1.33	3.15	2.99	2.49

cotton (Anzali harbor, 1.73 mm day<sup>-1</sup>). Cotton is a tropical plant and it cannot tolerate cold conditions, but there is another problem. In tropical regions of Iran, water shortage created

critical conditions for this crop. In recent decades, this crop lost its self-situation in crop rotation and was just cultivated in small farms (Table 8). The stations with green color have good



**Table 7** Calculated ET<sub>O</sub>, AE (for initial, middle, and end of crop growth stages), and ET<sub>C</sub> rates for oil crops

Station	ET <sub>O</sub>	Sunflower				Soybean				Canola			
		AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>
Abadan	8.29	2.90	8.91	2.90	4.90	3.32	9.53	4.15	5.67	2.90	10.8	2.90	5.53
Ahwaz	8.05	2.82	8.65	2.82	4.76	3.22	9.26	4.03	5.50	2.82	10.5	2.82	5.38
Lengeh harbor	5.84	2.04	6.28	2.04	3.45	2.34	9.26	2.92	4.84	2.04	7.59	2.04	3.89
Abbas harbor	5.74	2.01	6.17	2.01	3.40	2.30	6.72	2.87	3.96	2.01	7.46	2.01	3.83
Bushehr	5.20	1.82	5.59	1.82	3.08	2.08	6.60	2.60	3.76	1.82	6.76	1.82	3.47
Chabahar	10.71	3.75	11.5	3.75	6.33	4.28	5.98	5.36	5.21	3.75	13.9	3.75	7.13
Iranshahr	7.30	2.56	7.85	2.56	4.32	2.92	12.3	3.65	6.29	2.56	9.49	2.56	4.87
Kerman	7.03	2.46	7.56	2.46	4.16	2.81	8.40	3.52	4.91	2.46	9.14	2.46	4.69
Tabas	5.74	2.01	6.17	2.01	3.40	2.30	8.08	2.87	4.42	2.01	7.46	2.01	3.83
Yazd	6.95	2.43	7.47	2.43	4.11	2.78	6.60	3.48	4.29	2.43	9.04	2.43	4.63
Zabol	10.34	3.62	11.1	3.62	6.11	4.14	7.99	5.17	5.77	3.62	13.4	3.62	6.88
Bam	7.65	2.68	8.22	2.68	4.53	3.06	11.9	3.83	6.26	2.68	9.95	2.68	5.10
Dezful	6.88	2.41	7.40	2.41	4.07	2.75	8.80	3.44	5.00	2.41	8.94	2.41	4.59
Fasa	5.80	2.03	6.24	2.03	3.43	2.32	7.91	2.90	4.38	2.03	7.54	2.03	3.87
Isfahan	5.75	2.01	6.18	2.01	3.40	2.30	6.67	2.88	3.95	2.01	7.48	2.01	3.83
Kashan	3.67	1.28	3.95	1.28	2.17	1.47	6.61	1.84	3.31	1.28	4.77	1.28	2.44
Sabzevar	6.99	2.45	7.51	2.45	4.14	2.80	4.22	3.50	3.51	2.45	9.09	2.45	4.66
Semnan	4.62	1.62	4.97	1.62	2.74	1.85	8.04	2.31	4.07	1.62	6.01	1.62	3.08
Shahrud	4.91	1.72	5.28	1.72	2.91	1.96	5.31	2.46	3.24	1.72	6.38	1.72	3.27
Torbathaidarieh	5.45	1.91	5.86	1.91	3.23	2.18	5.65	2.73	3.52	1.91	7.09	1.91	3.64
Zahedan	7.51	2.63	8.07	2.63	4.44	3.00	6.27	3.76	4.34	2.63	9.76	2.63	5.01
Abadeh	5.75	2.01	6.18	2.01	3.40	2.30	8.64	2.88	4.61	2.01	7.48	2.01	3.83
Arak	3.59	1.26	3.86	1.26	2.13	1.44	6.61	1.80	3.28	1.26	4.67	1.26	2.40
Anzali harbor	2.44	0.85	2.62	0.85	1.44	0.98	4.13	1.22	2.11	0.85	3.17	0.85	1.62
Birjand	6.52	2.28	7.01	2.28	3.86	2.61	2.81	3.26	2.89	2.28	8.48	2.28	4.35
Bojnord	3.35	1.17	3.60	1.17	1.98	1.34	7.50	1.68	3.51	1.17	4.36	1.17	2.23
Ghazvin	3.69	1.29	3.97	1.29	2.18	1.48	3.85	1.85	2.39	1.29	4.80	1.29	2.46
Gorgan	3.16	1.11	3.40	1.11	1.87	1.26	4.24	1.58	2.36	1.11	4.11	1.11	2.11
Hamedan	3.62	1.27	3.89	1.27	2.14	1.45	3.63	1.81	2.30	1.27	4.71	1.27	2.42
Kermanshah	5.42	1.90	5.83	1.90	3.21	2.17	4.16	2.71	3.01	1.90	7.05	1.90	3.62
Khoramabad	5.38	1.88	5.78	1.88	3.18	2.15	6.23	2.69	3.69	1.88	6.99	1.88	3.58
Mashhad	6.91	2.42	7.43	2.42	4.09	2.76	6.19	3.46	4.14	2.42	8.98	2.42	4.61
Noshahr	2.50	0.88	2.69	0.88	1.48	1.00	7.95	1.25	3.40	0.88	3.25	0.88	1.67
Ramsar	2.51	0.88	2.70	0.88	1.49	1.00	2.88	1.26	1.71	0.88	3.26	0.88	1.67
Rasht	2.96	1.04	3.18	1.04	1.75	1.18	2.89	1.48	1.85	1.04	3.85	1.04	1.98
Shiraz	6.94	2.43	7.46	2.43	4.11	2.78	3.40	3.47	3.22	2.43	9.02	2.43	4.63
Tabriz	3.05	1.07	3.28	1.07	1.81	1.22	7.98	1.53	3.58	1.07	3.97	1.07	2.04
Tehran	6.04	2.11	6.49	2.11	3.57	2.42	3.51	3.02	2.98	2.11	7.85	2.11	4.02
Ardabil	2.76	0.97	2.97	0.97	1.64	1.10	6.95	1.38	3.14	0.97	3.59	0.97	1.84
Khoy	3.26	1.14	3.50	1.14	1.93	1.30	3.17	1.63	2.03	1.14	4.24	1.14	2.17
Sanandaj	3.84	1.34	4.13	1.34	2.27	1.54	3.75	1.92	2.40	1.34	4.99	1.34	2.56
Shahrekord	3.80	1.33	4.09	1.33	2.25	1.52	4.42	1.90	2.61	1.33	4.94	1.33	2.53
Uromieh	3.06	1.07	3.29	1.07	1.81	1.22	4.37	1.53	2.37	1.07	3.98	1.07	2.04
Zanjan	3.32	1.16	3.57	1.16	1.96	1.33	3.52	1.66	2.17	1.16	4.32	1.16	2.21

conditions for cultivation of crops based on ET<sub>O</sub> and ET<sub>C</sub> values. In contrast, the stations with red color have critical conditions and, therefore, crops cultivation have high costs and government should save against erosion by using range plants (Fig. 1a–n).

Annual average rainfall (mm year<sup>-1</sup>) and ET<sub>O</sub> (mm year<sup>-1</sup>) are 76.56 and 3001, respectively, in stations with very dry climate; 195.41 and 2249, respectively, in stations with dry climate; 343.9 and 1351, respectively, in stations with semi-

**Table 8** Calculated ET<sub>O</sub>, AE (for initial, middle, and end of crop growth stages), and ET<sub>C</sub> rates for sugar beet, potato, and cotton

Station	ET <sub>O</sub>	Sugar beet				Potato				Cotton			
		AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>	AE <sub>ini</sub>	AE <sub>mid</sub>	AE <sub>end</sub>	ET <sub>C</sub>
Abadan	8.29	2.90	9.95	5.80	6.22	4.15	9.53	6.22	6.63	2.90	9.74	4.97	5.87
Ahwaz	8.05	2.82	9.66	5.64	6.04	4.03	9.26	6.04	6.44	2.82	9.46	4.83	5.70
Lengeh harbor	5.84	2.04	7.01	4.09	4.38	2.92	9.26	4.38	5.52	2.04	6.86	3.50	4.13
Abbas harbor	5.74	2.01	6.89	4.02	4.31	2.87	6.72	4.31	4.63	2.01	6.74	3.44	4.06
Bushehr	5.20	1.82	6.24	3.64	3.90	2.60	6.60	3.90	4.37	1.82	6.11	3.12	3.68
Chabahar	10.71	3.75	12.8	7.50	8.02	5.36	5.98	8.03	6.46	3.75	12.6	6.43	7.59
Iranshahr	7.30	2.56	8.76	5.11	5.48	3.65	12.3	5.48	7.14	2.56	8.58	4.38	5.17
Kerman	7.03	2.46	8.44	4.92	5.27	3.52	8.40	5.27	5.73	2.46	8.26	4.22	4.98
Tabas	5.74	2.01	6.89	4.02	4.31	2.87	8.08	4.31	5.09	2.01	6.74	3.44	4.06
Yazd	6.95	2.43	8.34	4.87	5.21	3.48	6.60	5.21	5.10	2.43	8.17	4.17	4.92
Zabol	10.34	3.62	12.4	7.24	7.75	5.17	7.99	7.76	6.97	3.62	12.2	6.20	7.34
Bam	7.65	2.68	9.18	5.36	5.74	3.83	11.9	5.74	7.16	2.68	8.99	4.59	5.42
Dezful	6.88	2.41	8.26	4.82	5.16	3.44	8.80	5.16	5.80	2.41	8.08	4.13	4.87
Fasa	5.80	2.03	6.96	4.06	4.35	2.90	7.91	4.35	5.05	2.03	6.82	3.48	4.11
Isfahan	5.75	2.01	6.90	4.03	4.31	2.88	6.67	4.31	4.62	2.01	6.76	3.45	4.07
Kashan	3.67	1.28	4.40	2.57	2.75	1.84	6.61	2.75	3.73	1.28	4.31	2.20	2.60
Sabzevar	6.99	2.45	8.39	4.89	5.24	3.50	4.22	5.24	4.32	2.45	8.21	4.19	4.95
Semnan	4.62	1.62	5.54	3.23	3.46	2.31	8.04	3.47	4.61	1.62	5.43	2.77	3.27
Shahrud	4.91	1.72	5.89	3.44	3.68	2.46	5.31	3.68	3.82	1.72	5.77	2.95	3.48
Torbathaidarieh	5.45	1.91	6.54	3.82	4.09	2.73	5.65	4.09	4.16	1.91	6.40	3.27	3.86
Zahedan	7.51	2.63	9.01	5.26	5.63	3.76	6.27	5.63	5.22	2.63	8.82	4.51	5.32
Abadeh	5.75	2.01	6.90	4.03	4.31	2.88	8.64	4.31	5.28	2.01	6.76	3.45	4.07
Arak	3.59	1.26	4.31	2.51	2.69	1.80	6.61	2.69	3.70	1.26	4.22	2.15	2.54
Anzali harbor	2.44	0.85	2.93	1.71	1.83	1.22	4.13	1.83	2.39	0.85	2.87	1.46	1.73
Birjand	6.52	2.28	7.82	4.56	4.89	3.26	2.81	4.89	3.65	2.28	7.66	3.91	4.62
Bojnord	3.35	1.17	4.02	2.35	2.51	1.68	7.50	2.51	3.90	1.17	3.94	2.01	2.37
Ghazvin	3.69	1.29	4.43	2.58	2.77	1.85	3.85	2.77	2.82	1.29	4.34	2.21	2.61
Gorgan	3.16	1.11	3.79	2.21	2.37	1.58	4.24	2.37	2.73	1.11	3.71	1.90	2.24
Hamedan	3.62	1.27	4.34	2.53	2.71	1.81	3.63	2.72	2.72	1.27	4.25	2.17	2.56
Kermanshah	5.42	1.90	6.50	3.79	4.06	2.71	4.16	4.07	3.65	1.90	6.37	3.25	3.84
Khoramabad	5.38	1.88	6.46	3.77	4.04	2.69	6.23	4.04	4.32	1.88	6.32	3.23	3.81
Mashhad	6.91	2.42	8.29	4.84	5.18	3.46	6.19	5.18	4.94	2.42	8.12	4.15	4.90
Noshahr	2.50	0.88	3.00	1.75	1.88	1.25	7.95	1.88	3.69	0.88	2.94	1.50	1.77
Ramsar	2.51	0.88	3.01	1.76	1.88	1.26	2.88	1.88	2.01	0.88	2.95	1.51	1.78
Rasht	2.96	1.04	3.55	2.07	2.22	1.48	2.89	2.22	2.20	1.04	3.48	1.78	2.10
Shiraz	6.94	2.43	8.33	4.86	5.21	3.47	3.40	5.21	4.03	2.43	8.15	4.16	4.91
Tabriz	3.05	1.07	3.66	2.14	2.29	1.53	7.98	2.29	3.93	1.07	3.58	1.83	2.16
Tehran	6.04	2.11	7.25	4.23	4.53	3.02	3.51	4.53	3.69	2.11	7.10	3.62	4.28
Ardabil	2.76	0.97	3.31	1.93	2.07	1.38	6.95	2.07	3.47	0.97	3.24	1.66	1.96
Khoy	3.26	1.14	3.91	2.28	2.44	1.63	3.17	2.45	2.42	1.14	3.83	1.96	2.31
Sanandaj	3.84	1.34	4.61	2.69	2.88	1.92	3.75	2.88	2.85	1.34	4.51	2.30	2.72
Shahrekorrd	3.80	1.33	4.56	2.66	2.85	1.90	4.42	2.85	3.06	1.33	4.47	2.28	2.69
Uromieh	3.06	1.07	3.67	2.14	2.29	1.53	4.37	2.30	2.73	1.07	3.60	1.84	2.17
Zanjan	3.32	1.16	3.98	2.32	2.49	1.66	3.52	2.49	2.56	1.16	3.90	1.99	2.35

dry climate; 583.8 and 1153, respectively, in stations with semi-humid climate; and 1272 and 949, respectively, in stations with semi-dry climate. The maximum and

minimum of annual average rainfall happened in Rasht (1337.5 mm year<sup>-1</sup>) and Zabol (57.7 mm year<sup>-1</sup>) stations, and the maximum and minimum of annual

**Table 9** The annual mean precipitation, potential evapotranspiration, and aridity index<sub>(UNESCO)</sub> (1980–2010) in synoptic stations for Iran climatic conditions

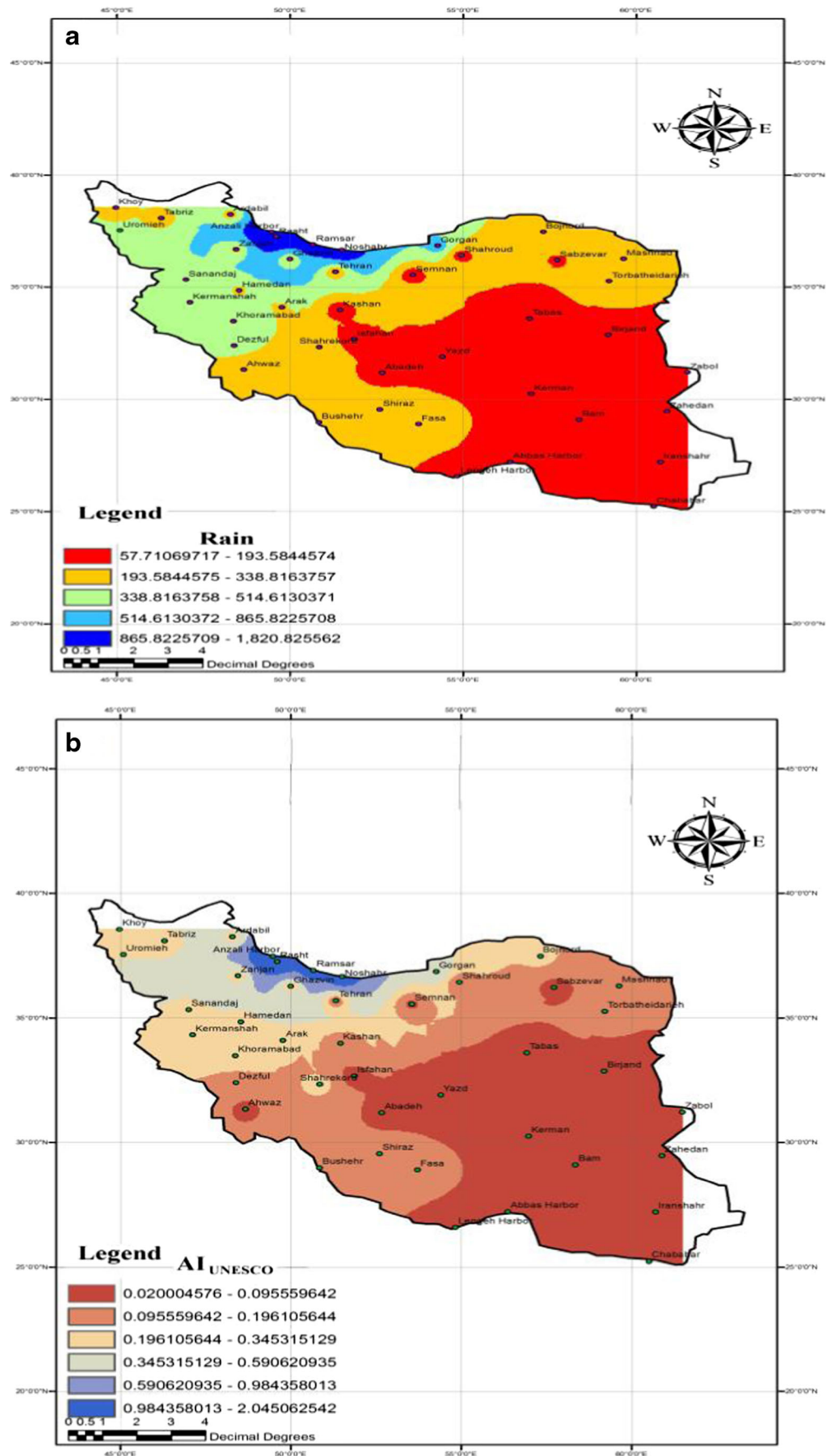
Region	Station	Aridity index <sub>(UNESCO)</sub>		
		Precipitation (mm year <sup>-1</sup> )	ET <sub>O</sub> (mm year <sup>-1</sup> )	AI
Very dry	Chabahar	118	3909.15	0.03
	Yazd	59.2	2536.75	0.02
	Zabol	57.7	3025.85	0.02
	Bam	58.8	2792.25	0.02
	Zahedan	89.3	2741.15	0.03
Dry	Abadan	153.3	3025.85	0.05
	Ahwaz	209.2	2938.25	0.07
	Lengeh harbor	136.9	2131.60	0.06
	Abbas harbor	176.1	2095.10	0.08
	Bushehr	268	1898.00	0.14
	Iranshahr	111.9	2664.50	0.04
	Kerman	148	2565.95	0.06
	Tabas	82.2	2095.10	0.04
	Dezful	394.6	2511.2	0.16
	Fasa	289.9	2117	0.14
	Isfahan	125	2098.75	0.06
	Kashan	136	1339.55	0.10
	Sabzevar	186.6	2551.35	0.07
	Semnan	140.7	1686.3	0.08
	Shahroud	153.3	1792.15	0.09
	Torbatheidarieh	267.6	1989.25	0.13
	Abadeh	137	2098.75	0.07
	Birjand	168.5	2379.8	0.07
	Mashhad	251.5	2522.15	0.10
	Shiraz	334.7	2533.1	0.13
Tehran	232.7	2204.6	0.10	
Semi Dry	Arak	337.1	1310.35	0.26
	Bojnord	267.8	1222.75	0.22
	Ghazvin	314.4	1346.85	0.23
	Hamedan	317.7	1321.3	0.24
	Kermanshah	439.2	1978.3	0.22
	Khoramabad	504.3	1963.7	0.26
	Tabriz	283.8	1113.25	0.25
	Ardabil	295.5	1007.4	0.29
	Khoy	289.2	1189.9	0.24
	Sanandaj	449.9	1401.6	0.32
	Shahrekord	321.8	1387	0.23
	Uromieh	338.9	1116.9	0.30
Zanjan	311.1	1211.8	0.26	
Semi Humid	Gorgan	583.8	1153.4	0.51
Very Humid	Anzali harbor	1830.5	890.6	2.06
	Noshahr	1272.8	912.5	1.39
	Ramsar	1206.2	916.15	1.24
	Rasht	1337.5	1080.4	1.23

All data are significant at five levels of percentages

average ET<sub>O</sub> happened in Chabahar (3909 mm year<sup>-1</sup>) and Anzali harbor (890 mm year<sup>-1</sup>), respectively (Table 9, Fig. 2).

The maximum ET<sub>O</sub> happened in Chabahar (10.71 mm day<sup>-1</sup>) and Zabol (10.34 mm day<sup>-1</sup>) stations, and the minimum happened in Anzali harbor (2.44 mm day<sup>-1</sup>), Noshahr

**Fig. 2** The annual mean precipitation (a) and aridity index<sub>(UNESCO)</sub> (b) (1980–2010) in synoptic stations for Iran climatic conditions



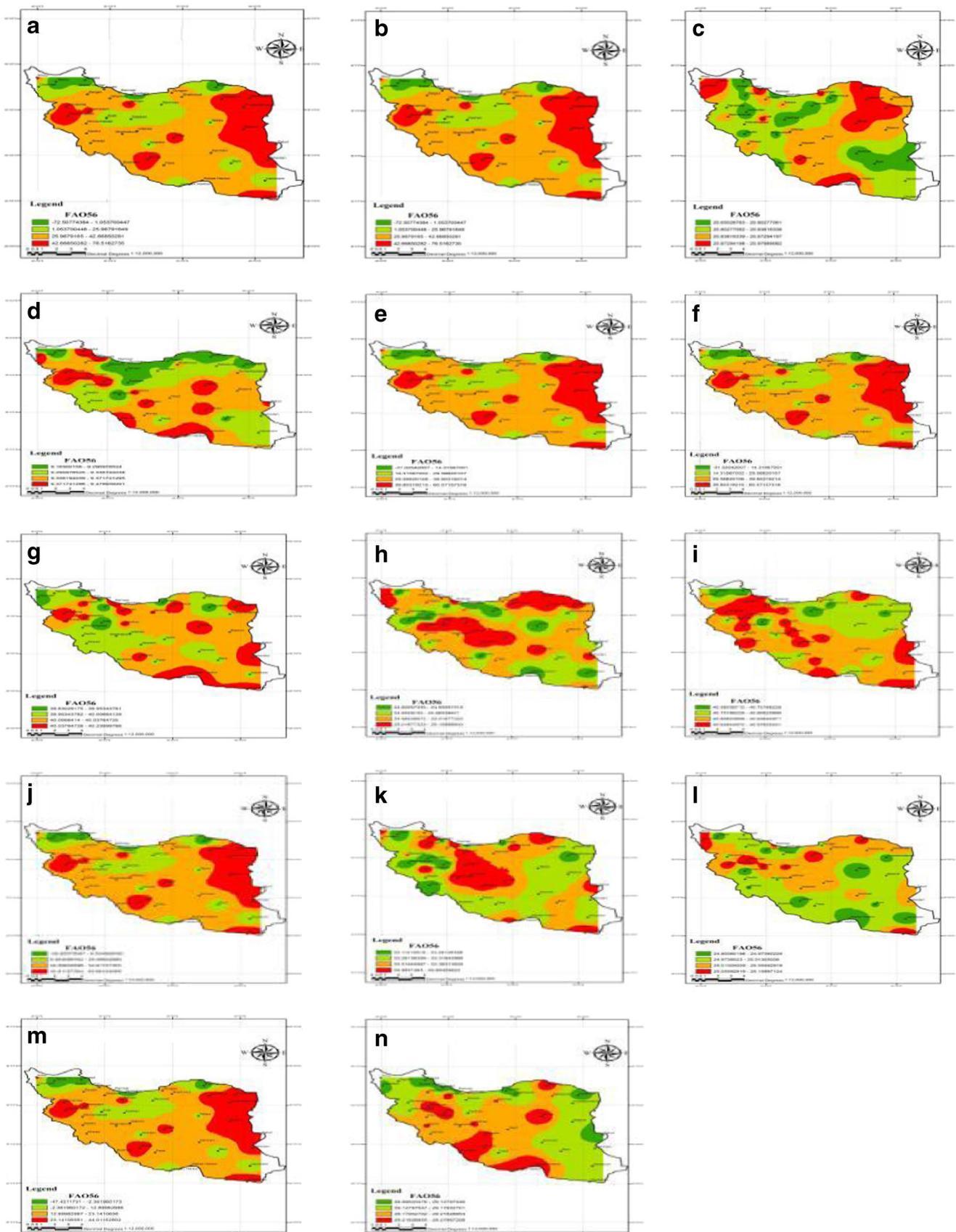
(2.5 mm day<sup>-1</sup>), and Ramsar (2.51 mm day<sup>-1</sup>) stations (Table 5). For calculations of precipitations, Iran climate was divided into five zones (AI<sub>UNESCO</sub>): 17 stations in dry region (47.72 %), 13 stations in semi-dry region (29.54 %), 5 stations in very dry region (11.36 %; lost

zones), 4 stations in very humid region (9.09 %), and 1 station (Gorgan) in semi-humid region. Therefore, 13.63 % of stations have suitable conditions for crop productions and 86.37 % are in critical conditions (Table 9). The stations with blue color have high rain

**Table 10** Estimated aridity index based on the FAO<sub>56</sub> report for cereals and leguminous crop

Station	Wheat	Barley	Com	Rice	Bean	Chickpea	Lentil	Alfalfa
Abadan	37.52	43.31	20.87	9.288	36.67	36.67	39.93	24.97
Ahwaz	37.52	43.35	20.87	9.317	36.65	36.65	40.00	24.97
Lengeh harbor	13.87	28.77	20.89	9.418	22.09	22.09	40.07	25.00
Abbas harbor	36.41	42.68	20.91	9.408	35.89	35.89	40.07	24.91
Bushehr	30.96	39.42	20.77	9.423	32.69	32.69	40.00	25.00
Chabahar	69.65	63.03	20.82	9.337	56.40	56.40	40.06	25.02
Iranshahr	8.36	25.48	20.82	9.315	18.77	18.77	40.00	24.93
Kerman	35.14	41.82	20.77	9.388	35.14	35.14	39.97	25.04
Tabas	23.52	34.67	20.91	9.408	28.05	28.05	40.07	24.91
Yazd	48.35	50.07	20.86	9.353	43.31	43.31	40.00	25.04
Zabol	58.03	55.90	20.79	9.381	49.23	49.23	40.04	24.95
Bam	15.56	29.80	20.78	9.281	23.14	23.14	40.00	24.97
Dezful	30.52	39.10	20.78	9.302	32.41	32.41	39.97	25.00
Fasa	25.86	36.21	20.86	9.310	29.48	29.48	40.00	25.00
Isfahan	36.87	42.96	20.87	9.391	36.35	36.35	40.00	25.04
Kashan	2.18	21.53	20.71	9.264	14.99	14.99	40.05	25.07
Sabzevar	67.24	61.52	20.89	9.299	54.79	54.79	39.91	25.04
Semnan	5.41	23.59	20.78	9.307	16.88	16.88	40.04	24.89
Shahroud	41.14	45.62	20.77	9.369	38.90	38.90	40.12	25.05
Torbatheidarieh	43.67	47.16	20.92	9.358	40.37	40.37	40.00	24.95
Zahedan	54.59	53.79	20.77	9.321	47.14	47.14	40.08	25.03
Abadeh	18.43	31.65	20.87	9.391	24.87	24.87	40.00	25.04
Arak	0.00	20.33	20.89	9.471	13.65	13.65	39.83	25.07
Anzali harbor	8.20	25.41	20.90	9.426	18.44	18.44	40.16	25.00
Birjand	76.53	67.33	20.86	9.356	60.58	60.58	40.03	25.00
Bojnord	-21.79	7.16	20.90	9.254	0.30	0.30	40.00	25.07
Ghazvin	43.36	46.88	20.87	9.214	40.11	40.11	39.84	24.93
Gorgan	26.90	37.03	20.89	9.177	30.38	30.38	39.87	25.00
Hamedan	45.30	48.34	20.72	9.392	41.44	41.44	40.06	24.86
Kermanshah	58.30	56.09	20.85	9.410	49.45	49.45	40.04	24.91
Khoramabad	36.99	43.12	20.82	9.294	36.43	36.43	39.96	25.09
Mashhad	51.37	51.81	20.84	9.262	45.15	45.15	40.09	25.04
Noshahr	-72.80	-24.40	20.80	9.200	-31.20	-31.20	40.00	24.80
Ramsar	37.85	43.43	20.72	9.163	36.65	36.65	40.24	25.10
Rasht	46.96	48.99	20.95	9.459	42.57	42.57	39.86	25.00
Shiraz	73.34	65.27	20.89	9.366	58.65	58.65	40.06	24.93
Tabriz	-42.30	-5.57	20.98	9.180	-12.13	-12.13	40.00	24.92
Tehran	68.38	62.25	20.86	9.272	55.63	55.63	40.07	25.00
Ardabil	-36.96	-2.17	20.65	9.420	-9.06	-9.06	39.86	25.00
Khoy	46.93	49.39	20.86	9.202	42.64	42.64	39.88	25.15
Sanandaj	46.88	49.22	20.83	9.375	42.45	42.45	40.10	25.00
Shahrekord	36.84	42.89	20.79	9.211	36.32	36.32	40.00	25.00
Uromieh	22.22	33.99	20.92	9.477	27.45	27.45	39.87	25.16
Zanjan	42.47	46.39	20.78	9.337	39.76	39.76	40.06	25.00

The numbers in italic mean that the station is suitable for rainfed farming



**Fig. 3** The maps of  $AI_{(FAO56)}$  for wheat (a), barley (b), corn (c), rice (d), bean (e), chickpea (f), lentil (g), alfalfa (h), sunflower (i), soybean (j), canola (k), sugar beet (l), potato (m), and cotton (n) in Iran climatic conditions (1980–2010)

(costal Caspian Sea) because of having moderate weather. Also, the rain content decreased from northwest to southeast of country, respectively (Fig. 2a). Based on the aridity index<sub>UNESCO</sub>, two thirds of Iran have critical conditions and the farmers cannot cultivate all crops and

therefore cultivate few crops (for example, wheat, barley, bean, pea, or range and medicinal plants) (Fig. 2b).

According to determined indices (Table 3), the stations of Kashan, Arak, Bojnord, Noshahr, Tabriz, and Ardabil are suitable for wheat cultivation and the stations of

**Table 11** Estimated aridity index based on the FAO<sub>56</sub> report for industrial crops

Station	Sunflower	Soybean	Canola	Sugar beet	Potato	Cotton
Abadan	40.89	31.60	33.29	24.97	20.02	29.19
Ahwaz	40.87	31.68	33.17	24.97	20.00	29.19
Lengeh harbor	40.92	17.12	33.39	25.00	5.48	29.28
Abbas harbor	40.77	31.01	33.28	24.91	19.34	29.27
Bushehr	40.77	27.69	33.27	25.00	15.96	29.23
Chabahar	40.90	51.35	33.43	25.12	39.68	29.13
Iranshahr	40.82	13.84	33.29	24.93	2.19	29.18
Kerman	40.83	30.16	33.29	25.04	18.49	29.16
Tabas	40.77	23.00	33.28	24.91	11.32	29.27
Yazd	40.86	38.27	33.38	25.04	26.62	29.21
Zabol	40.91	44.20	33.46	25.05	32.59	29.01
Bam	40.78	18.17	33.33	24.97	6.41	29.15
Dezful	40.84	27.33	33.28	25.00	15.70	29.22
Fasa	40.86	24.48	33.28	25.00	12.93	29.14
Isfahan	40.87	31.30	33.39	25.04	19.65	29.22
Kashan	40.87	9.81	33.51	25.07	<i>-1.63</i>	29.16
Sabzevar	40.77	49.79	33.33	25.04	38.20	29.18
Semnan	40.69	11.90	33.33	25.11	0.22	29.22
Shahroud	40.73	34.01	33.40	25.05	22.20	29.12
Torbatheidarieh	40.73	35.41	33.21	24.95	23.67	29.17
Zahedan	40.88	42.21	33.29	25.03	30.49	29.16
Abadeh	40.87	19.83	33.39	25.04	8.17	29.22
Arak	40.67	8.64	33.15	25.07	<i>-3.06</i>	29.25
Anzali harbor	40.98	13.52	33.61	25.00	2.05	29.10
Birjand	40.80	55.67	33.28	25.00	44.02	29.14
Bojnord	40.90	<i>-4.78</i>	33.43	25.07	<i>-16.42</i>	29.25
Ghazvin	40.92	35.23	33.33	24.93	23.58	29.27
Gorgan	40.82	25.32	33.23	25.00	13.61	29.11
Hamedan	40.88	36.46	33.15	25.14	24.86	29.28
Kermanshah	40.77	44.46	33.21	25.09	32.66	29.15
Khoramabad	40.89	31.41	33.46	24.91	19.70	29.18
Mashhad	40.81	40.09	33.29	25.04	28.51	29.09
Noshahr	40.80	<i>-36.00</i>	33.20	24.80	<i>-47.60</i>	29.20
Ramsar	40.64	31.87	33.47	25.10	19.92	29.08
Rasht	40.88	37.50	33.11	25.00	25.68	29.05
Shiraz	40.78	53.60	33.29	24.93	41.93	29.25
Tabriz	40.66	<i>-17.38</i>	33.11	24.92	<i>-28.85</i>	29.18
Tehran	40.89	50.66	33.44	25.00	38.91	29.14
Ardabil	40.58	<i>-13.77</i>	33.33	25.00	<i>-25.72</i>	28.99
Khoy	40.80	37.73	33.44	25.15	25.77	29.14
Sanandaj	40.89	37.50	33.33	25.00	25.78	29.17
Shahrekord	40.79	31.32	33.42	25.00	19.47	29.21
Uromieh	40.85	22.55	33.33	25.16	10.78	29.08
Zanjan	40.96	34.64	33.43	25.00	22.89	29.22

The numbers in italic means that the station is suitable for rainfed farming

Noshahr, Tabriz, and Ardabil are suitable for barley, bean, and chickpea cultivation by rainfed farming systems. Unfortunately, natural and climatic conditions for corn and rice are not provided. Corn has the same conditions in all stations, but the deterrent factors are high temperature and water supplement (irrigation farming) especially for rice (Table 10, Fig. 3).

The climatic conditions for sunflower, canola, sugar beet, and cotton are dry and very dry. Therefore, they cannot tolerate water deficit, and the farmers have to irrigate their farms (Table 11). But, in relation to soybean, the stations of Bojnord, Noshahr, Tabriz, and Ardabil have good situation. Kashan, Arak, Bojnord, Noshahr, Tabriz, and Ardabil stations were suitable for potato (Table 11). Based on the FAO<sub>56</sub> index, the farmers cannot cultivate all crops, because in the northwest, temperature is a limited factor for few crops (for example, soybean, cotton, rice, and corn), and in the south, southeast, and southwest, humidity (water) is a limited factor (for example, canola, sugar beet, and potato). Also, in these regions, temperature has good conditions, and therefore, the farmers can cultivate corn, cotton, and soybean (if water is sufficient) (Fig. 3a–n).

## Conclusions

The results showed that the west, north, and northwest regions of Iran have good conditions for selected crops, but in regions of south, southwest, and southeast because of high evapotranspiration and water shortage, agriculture is reduced and farmers cannot cultivate all crops and they have to select few crops, for instance special cultivars of wheat, barley, and alfalfa, thus reducing agrobiodiversity. Finally, sustainable agriculture has been threatened by erosion, drought, and immigration of farmers to cities. Therefore, drought management should not be treated as an isolated problem but as an integral and key factor in sustainable agriculture. Farmers should be encouraged to develop a range of flexible contingency plans that protect the soil, climate, and vegetation. By having numerous contingency plans, farmers can resist the temptation of over extracting these resources. As mentioned above, drought monitoring requires synthesis of more drought indices. The inputs are streamflow, daily soil moisture model, crop moisture index, percent of normal precipitation, topsoil model, and remotely sensed satellite vegetation health index. Therefore, the system calculates daily evapotranspiration (Penman-Monteith formula) and uses this result and precipitation measurements to derive the accumulated climatological water shortage. From water shortage, we can calculate the water demand of different plants. And finally, food security monitoring in Iran provides the early warning needed to save lives in the face of a wide range of potential socioeconomic and environmental risks. Climate monitoring and forecasting are

especially important, given the large number of people dependent on subsistence agriculture.

After drought management by early warning system (EWS), sustainable agriculture procedures include soil and water conservation programs, choosing production systems based on land use capability classification, increased cropping intensity either through harvesting excess rainwater through surface runoff or by improving the groundwater recharge through percolation tanks, and good crop husbandry.

**Acknowledgments** This study was performed as part of our researches and supported by the Zabol University. The authors wish to thank the reviewers for their valuable comments.

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