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Investigating the Variations in Water Requirement for Main Plants in the Cultivation Pattern (Case Study: Kashmar Plain of Khorasan Razavi)

Hadi Dehghan[a], Somayeh Galdavi[a&*]

[a]Assistant Professor, Department of Water Engineering, Kashmar Higher Education Institute, Kashmar, Iran.

[*]Corresponding Author, E-mail address: s.galdavi@kashmar.ac.ir

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Abstract

The agricultural sector is crucial to Iran's economy, especially in ensuring food security. Climate changes, intense competition for water resources among various sectors, and the declining share of renewable resources in the agricultural sector make managing water consumption in agriculture essential. When doing so, it's important to consider changes in plant water needs. This study investigated the process of changing the water requirement of plants in the cultivation pattern in the Kashmar Plain by calculating evapotranspiration. These plants are including Sunflower, Leafy vegetables, Potato, Apple, Lentils, Walnut, Pears, Wheat, Tomato, Cherries, Peach, Watermelon, Peas, Vegetables, Pistachio, Plum, Pomegranate, Grape, Almonds, Eggplant, Cotton, Onion, Barley, Sugar beet, Melon, Spring cucumber, Autumn cucumber, Fodder corn, Saffron, and Cantaloupe. Firstly, the reference evapotranspiration was calculated on a daily scale over 20 years (1998 to 2017) using the FAO Penman Monteith equation. Then, monthly, seasonal, and annual values were used for calculations, and cultivated plants' evapotranspiration (water requirement) (ET_c) was determined. The Mann-Kendall test was utilized to examine the changes in Evapotranspiration of plants. The results indicated an increasing trend in the water requirement of plants in the region. The greatest increases were observed in Evapotranspiration for autumn cucumber plants (54.8% increase), sugar beet (41.51% increase), and pistachio (38% increase), while the lowest increase was seen in almonds at 3.07%. After analyzing the data, it was found that pomegranates (19.94% increase) and lentils (20.54% increase) have the lowest increase in evaporation, transpiration, and water requirement. This suggests that changes in the cultivation pattern of the region may be necessary due to the varying water requirements of different plants. The findings of this research could be valuable in making decisions about the cultivation pattern of plants in the region.

Keywords: Cultivation pattern, Dry climate, Evapotranspiration, Kashmar plain, Water demand changes.

1. Introduction

Climate change has caused significant freshwater shortages, posing risks to agriculture in arid and semi-arid regions (Khondoker et al., 2023; Javadi et al., 2023). The agricultural sector is of special importance in Iran's economy, accounting for 7.4% of the gross domestic product and employing 13% of the country's total workforce. It plays a crucial role in ensuring food security. However, it is also the largest consumer of water in the country. Climate change, intense competition for water resources among different sectors, and the decreasing availability of renewable water sources have made it essential to manage water usage in agriculture while considering the changing water needs of plants. The water needs of plants are closely tied to the climate of each region (Acharjee et al., 2017a). Climate change is a significant issue among Middle Eastern countries, particularly in Iran. In the coming decades, Iran is projected to experience an increase of 2.6 °C in mean temperatures and a 35% decline in precipitation.

Iran is the leading country in the Middle East for total greenhouse gas (GHG) emissions, with nearly 616,741 million tons of

CO_2, making it the seventh highest in the world that is an important factorfor the mentioned climate change in Iran (Mansouri Daneshvar et al., 2019). So, it is crucial to study the potential impacts of recent climate changes on the water requirements of agricultural and horticultural crops for effective water resource management in the region. On a global scale, 70% of the total freshwater harvested is used for agricultural purposes (Fischer et al., 2007).

In the coming years, increased evapotranspiration from agriculture is expected due to anticipated changes in temperature, precipitation intensity, annual rainfall amounts, and the distribution of rainfall over time, as well as variations in atmospheric water vapor and soil water content. These changes will significantly impact the irrigation water requirements, particularly in semi-arid regions.

Understanding how climate change affects crop water requirements (CWR) is essential for addressing future challenges related to food security and the sustainability of water resources (El-Rawy et al., 2023). Therefore, it is important to research the effects of climate change on changes in plant water requirements. Regional studies on the impact of recent climate changes on the major products of the region are essential for local water management (Woznicki et al., 2015).

Furthermore, analyzing the trends in water demand of key plants in the region compared to the trends in evaporation-transpiration of the reference plant or climatic variables can provide a better understanding of recent climate-related changes in water demand.

To determine the water requirements of plants in a specific area, it is important to calculate the evapotranspiration value of a reference plant and then adjust it based on the specific plant being cultivated using a plant coefficient. In Iran, the agricultural sector has developed a comprehensive software called NETWAT to determine the net irrigation needs of crops. This software, based on the method recommended by the FAO organization, was prepared in 1999 and is still widely used for irrigation planning.

The data used in the software is based on a 25-year statistical period from 1970 to 1995. However, due to the growth of meteorology and the changes in climate over the past decade, there is a need to update and revise this important national work.

Several research works (Dehghan et al., 2018; Erfanian et al., 2019; Arab Salghar et al., 2010; Mohammadi et al., 2012; Masoompour et al., 2013; Akahvan et al., 2014; Jafarzadeh et al., 2016; Rahmani et al., 2015; Barzegari et al., 2017; Yaghoobzadeh et al., 2016; Brahimi et al., 2017; Acharjee et al., 2017b) conducted to study the changes in reference evapotranspiration and transpiration process, and the impact of climatic parameters on it.

These researches also evaluated the effect of climate change on net irrigation requirements and the alterations in water requirements for plants under current climatic conditions compared to the values provided in the NETWAT software.

For instance, Asadzadeh et al. (2016) conducted a study on the evaporation-transpiration process of a reference plant using Spearman's test at synoptic stations in Kurdistan province.

The findings revealed a significant increase in the annual trend of evaporation-transpiration at the Sanandaj station. The trend line slope for the Sanandaj, Zarineh, and Bijar stations displayed a positive trend across monthly, seasonal, and annual time series. Furthermore, a notable increasing trend was observed at these stations during the winter and summer seasons. In the six hottest months of the year, there was a statistically significant increase in the maximum temperature variable at the Sanandaj and Bijar stations.

The sensitivity analysis indicated that sunny hours and maximum temperature are the most significant factors influencing evaporation-transpiration during the hot months of the year.

In a study conducted by Barati et al. (2017), the net irrigation requirement of plants in the Kermanshah Plain cultivation pattern was estimated. When comparing the values obtained in this study with those available in the NETWAT software, it was found that, on average, the values obtained in the study were 1.2 times higher than those provided in the software.

Specifically, the ratio was approximately 2 for wheat and barley, and approximately 1 for clover, gram, cantaloupe, peas, and almonds.

The results of lysimetry research in the area confirm the accuracy of the calculations made in this study.

Barahimi and Ghazi (2018) updated and revised the national water document for the Qazvin and Fomanat plains. They calculated the water requirement of different crops as a pilot for the Qazvin Plain in Qazvin province (representative of dry areas of the country) and the Fomanat Plain in Gilan province (representative of humid areas of the country) using the Penman Monteith method recommended by the FAO for the statistical period from 1976 to 2005.

They compared the results with the National Water Document. The findings indicate that the annual potential evapotranspiration ranges from 1330 to 1587.1 mm in the Qazvin Plain and from 743 to 809 mm in the Fomanat Plain. On average, evapotranspiration is 40.6% higher in the Takstan station (as a sample station) in the Qazvin Plain compared to the National Water Document.

Acharjee et al. (2017a) examined rice water demand in northwest Bangladesh from 1980 to 2013 and found a significant reduction in reference evapotranspiration (ETo) during dry months due to increased humidity and decreased wind speed and sunshine. This led to a shorter plant growth period and a decline in potential evapotranspiration (ETc) for rice. The study indicated a varying trend in net irrigation requirements (ETC-ER) across regions, primarily linked to effective rainfall trends. Overall, the net irrigation requirement for rice decreased by an average of 4.4 mm per year, mainly due to a reduction in effective rainfall and evaporation-transpiration (9.5 mm per year).

It emphasized that changes in humidity, wind, and solar radiation can significantly influence agricultural water demand, countering the assumption that warmer air always increases water consumption. Acharjee et al. (2017b) investigated how climate change is expected to affect rice water demand in northwestern Bangladesh by calculating ET. Their study, which utilized various climate scenarios, found that while daily reference plant evapotranspiration is likely to increase due to higher temperatures, the potential evapotranspiration of rice plants (ET_C) is projected to decrease compared to the period from 1980 to 2013. This decrease is attributed to fewer growing days caused by rice plants' phenological response to elevated temperatures.

Nikbakht shahbazi (2019) conducted a study on the impact of climate change on precipitation and evaporation-transpiration of agricultural products in Khuzestan province. The findings revealed that the average temperature at all selected stations and scenarios increased by 4 degrees Celsius. Additionally, there was a decrease in average precipitation levels between 2060 and 2090. The study also observed an increasing trend in evaporation-transpiration for all agricultural products, with rice and grain corn showing a notable increase in 2060 and 2090.

Hussain et al. (2023) achieved a study to determine the water requirements and evapotranspiration rates for main crops, including rice, cotton, and wheat, cultivated in Punjab, Pakistan. The primary goal of this research was to improve water resource management in agriculture, which is the region's main economic activity. the results indicated that evapotranspiration rates ranged from 1.8 to 10.24 mm per day, while effective rainfall varied from 2 to 31.3 mm. The irrigation requirements for rice, cotton, and wheat were found to be 996.4 mm, 623.3 mm, and 209.5 mm, respectively. Among these crops, the total net irrigation needs were 72.4 mm for rice, 67.8 mm for cotton, and 44.1 mm for wheat, while the total gross irrigation requirements were 103.5 mm for rice, 99.8 mm for cotton, and 63 mm for wheat.

Based on the studies mentioned earlier, most research has focused on examining the process of reference evaporation-transpiration and its correlation with climatic data. However, there's limited research on the changes in evaporation-transpiration of crops based on available meteorological information. There hasn't been a study on determining the changes in irrigation needed for plants in the Kashmar Plain cultivation pattern under current climate conditions. Considering the critical water resources situation in the Kashmar Plain in Khorasan Razavi province and the lack of research on changes in water requirement for plants in

Kashmar city's cultivation pattern, the objectives of this research are as follows:

1. Investigating the monthly, seasonal, and annual changes in evapotranspiration and the climatic factors influencing it.
2. Analyzing the annual changes in Evapotranspiration of crops.
3. Comparing the long-term changes in evapotranspiration and transpiration of the main plants in the cultivation pattern of Kashmar city under current climatic conditions with the values provided in the NETWAT software.

2. Materials and Methods

2.1. Study area

In Khorasan Razavi province, the demand for water for agricultural production is the highest compared to other provinces in the country. The province has an average reservoir deficit of 1028 million cubic meters per year, which is the largest among all provinces. The total renewable water resources in the province are 2712 million cubic meters per year, with 592 million cubic meters from surface water and 2120 million cubic meters from underground water. In the water year 2019-2020, the total water withdrawal was 4769 million cubic meters, with 82.9% of it being used for agriculture (Khorasan Razavi Province Water Authority, 2019-2020). The Kashmar Plain in Khorasan Razavi Province is one of the critical prohibited plains, with an estimated reservoir deficit of 17.4 million cubic meters in the water year 2019-2020and an average of 33.69 million cubic meters over the statistical period.

The total renewable water resources in the Kashmar Plain amount to 53.4 million cubic meters per year, with 4.8 million cubic meters from surface water and 48.6 million cubic meters from underground sources. The total water withdrawal in the 2019-2020 water year is 100.3 million cubic meters, with 77.6% used for agricultural purposes (Kashmar water table, 2019-2020). Kashmar City covers an area of 1150 square kilometers and is situated 228 kilometers from the center of the province, between longitudes 58 degrees 7 minutes to 58 degrees 47 minutes east and latitudes 35 degrees to 35 degrees 52 minutes north.

The city has 11583 hectares of irrigated area, and 287 hectares of rainfed area, and produces 135 thousand tons of agricultural, horticultural, livestock, and aquatic products. Key agricultural and horticultural products of the city include wheat, barley, grapes, almonds, and saffron (State of water in Kashmar County, 2019-2020).

2.2. Research method

In this study, we aimed to understand the changing water requirement of plants and calculate the evaporation-transpiration of plants in the cultivation pattern in Kashmar Plain. Initially, the reference evaporation-transpiration daily was calculated using the FAO Penman-Monteith equation. The meteorological parameters used as input information for the calculation included maximum and minimum temperature (^{o}c), maximum and minimum relative humidity (%), daily sunshine hours, and wind speed at a height of two meters (m/s). It's important to note that in this study, first the reference evaporation-transpiration calculations on a daily scale over 20 years from 1998 to 2017 were performed, and then used monthly, seasonal, and annual values as the basis for the calculations.

To calculate the water requirement for growing specific plants (ET_c), the length of the growth periods and the corresponding plant coefficients (K_c) need to be determined. This involves multiplying the plant coefficient for each day by the reference evapotranspiration value for that day. This calculation was conducted by the following formula (Akhavan et al., 2016).

$$ET_c=K_c\times ET_o \qquad (1)$$

The growth periods of plants are divided into 4 stages, each with different plant K_c coefficients. The length of these periods depends on the type of plant varieties and is obtained from local information. For this study, data on planting dates, the length of growth periods, and plant coefficients for various crops were obtained from the OPTIWAT plant water requirement software collection (Akhavan et al., 2016). The crops investigated include barley, autumn cucumber, wheat, and saffron from winter crops, as well as spring products such as sunflower, eggplant, cotton, onion, sugar beet, melon, spring cucumber, fodder corn, vegetables, leafy vegetables, potatoes, and lentils, in addition to tomatoes, peas, watermelons, and garden products including plums, pomegranates, grapes, almonds, apples, walnuts, pears, cherries, peaches, and pistachios. These products were selected based on their cultivated area and are among the most important products grown in the Kashmar plain.

2.3. Mann-Kendall test

If (y_t) represents a series of annual values for a specific factor, where ($t=1, 2,\ldots, N$) (N is the number of statistical years), each value of (y'_t) such that $t=t'+1,\ t'+2,\ldots,\ N$ is compared with (y_t). Then, a new series (Z_k) is created with values of +1, 0, and -1 representing the conditions ($y_t > y'_t$), ($y_t = y'_t$), and ($y_t < y'_t$) respectively and $K=(t'-1)(2N-t')/2+(t-t')$. The Mann-Kendall statistic (u_c) is obtained from Eq. 2, where S is the sum of all Z_k (Eq. 2), $V(S)$ is the variance of S (Eq. 3), and the value of m is +1 or -1 depending on whether S is negative or positive.

$$u_c = \frac{S+m}{\sqrt{V(S)}} \tag{2}$$

$$V(S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{n} e_i(e_i-1)(2e_i+5)\right] \tag{3}$$

In Eq. 3: "N" represents the number of paired groups and "e_i" represents the number of observations in the i^th^ group. The method assumes that the statistic u_c is equal to 0 while S=0. If $|u_c| > u_{1}-\alpha/2$, and the $u_{1}-\alpha/2$ is from the quantile of $1-\alpha/2$ the standard normal distribution, where α represents the significance level, then the trend assumption cannot be rejected.

This test was used for analyzing data trend in many research and showed good results (Abie Diress and Besha Bedada (2021); Sudarsan and Lasitha (2023); Mamo et al. (2024)).

3. Results and Discussion

In this study, the changes in water requirement of plants in the cultivation pattern in Kashmar Plain were investigated by calculating evapotranspiration. To do this, the first reference evapotranspiration on a daily scale for 20 years (1998 to 2017) was calculated using the FAO Penman Monteith equation. Then, monthly, seasonal, and annual values as the basis of calculations to determine cultivated plants' evapotranspiration (water requirement) (ETc). Finally, the Mann-Kendall test was used to check for any changes in the process.

3.1. The process of changes in reference evapotranspiration and climatic parameters

In this research, the Mann-Kendall test was used to examine the variations in reference evapotranspiration and climatic parameters using monthly, seasonal, and annual data. The Z statistic values obtained from the Mann-Kendall test to assess the significance of the changes in climatic parameters are shown in Tables 1 to 3.

Table 1 indicates that there is a significant decreasing trend in the following parameters: sunny hours during April and May, maximum relative humidity in June, July, August, January, and February, and minimum relative humidity in May, June, July, August, September, October, November, December, January, and February, Minimum temperature in December. Also, the maximum temperature in June and August, the minimum temperature in June, the average temperature in June, and the wind speed and reference evapotranspiration have shown an increasing trend across all months.

According to Table 2, the seasonal analysis of the climatic parameters studied indicates a significant decreasing trend: the sunny hours in spring, maximum relative humidity in both summer and winter, and minimum relative humidity across all seasons. Additionally, the analysis reveals an increasing trend in minimum temperature during spring, as well as in wind speed and reference evapotranspiration throughout all seasons.

Table 3 shows that the analysis of climatic data from the meteorological station reveals significant trends: there is a significant decrease in sunny hours, maximum relative humidity, and minimum relative humidity. In contrast, wind speed and reference evapotranspiration demonstrate a significant increasing trend.

Table 1. Values of the Z-statistic obtained from the Mann-Kendall test at the Kashmar meteorological station (evapotranspiration monthly reference and climatic parameters)

Month	**Climatic parameter**							
	sunny hours	maximum Relative humidity	Minimum relative humidity	Maximum temperature	Minimum temperature	Average temperature	wind speed	Reference evapotranspiration
April	-1.72^{+}	0.29	-0.03	0	-0.36	-0.03	4.19***	2.37*
May	-1.78^{+}	-1.5	-2.14*	0.75	1.14	1.01	3.21**	3.34***
June	-1.2	-2.3*	-3.02**	2.69**	3.34***	3.34***	4.03***	4.06***
July	-1.2	-2.76**	-3.21**	0.49	0.88	0.62	3.54***	3.67***
August	0.42	-2.5*	-2.95**	1.75^{+}	0.42	1.4	2.86**	3.15**
September	-1.17	-1.04	-2.6**	-0.94	-1.27	-1.14	3.02**	3.93***
October	-1.46	-1.2	-2.11*	0.29	0.23	0.19	3.54***	3.47***
November	0.49	-0.36	-1.65^{+}	-0.55	-0.81	-0.88	3.51***	2.63**
December	1.27	-1.33	-1.72^{+}	-0.75	-2.11*	-1.2	4.06***	3.67***
January	1.46	-2.63**	-2.3*	0.03	-1.14	-0.16	3.54***	3.34***
February	-0.75	-2.69**	-1.91^{+}	1.2	0.75	0.81	3.61***	3.41***
March	-0.49	-0.84	-0.49	0.21	0.42	0.07	3.5***	2.38*

+, *, **, *** are significant respectively at the level of 10, 5, 1, and 0.1 percent.

Table 2. Values of the Z statistic obtained from the Mann-Kendall test at the Kashmar meteorological station (seasonal reference evapotranspiration and climatic parameters)

Season	**Climatic parameters**							
	sunny hours	maximum Relative humidity	Minimum relative humidity	Maximum temperature	Minimum temperature	Average temperature	wind speed	Reference evapotranspiration
spring	-2.63**	-0.94	-1.72^{+}	1.07	1.85^{+}	1.33	3.8***	3.41***
summer	-0.88	-2.69**	-3.47***	0.68	0.62	0.88	3.02**	3.8***
autumn	0.29	-1.59	-1.85^{+}	-0.29	-1.4	-0.81	4.12***	3.93***
winter	0	-2.5*	-2.17*	0.55	-0.29	0	3.99***	3.29**

+, *, **, *** are significant respectively at the level of 10, 5, 1, and 0.1 percent.

Table 3. Values of the Z statistic obtained from the Mann-Kendall test at the Kashmar meteorological station (evapotranspiration reference and climatic parameters on an annual scale)

Climatic parameters							
sunny hours	maximum Relative humidity	Minimum relative humidity	Maximum temperature	Minimum temperature	Average temperature	wind speed	Reference evapotranspiration
-1.89^{+}	-2.03*	-2.8**	0.49	-0.07	0.49	3.71***	3.64***

+, *, **, and *** are significant respectively at 10, 5, 1, and 0.1 percent.

So, the test results confirm changes in climatic parameters and reference Evapotranspiration values (Tables 1 to 3). These findings align with the research of Barahimi and Ghazi (2018), who utilized the FAO Penman Monteith method to calculate Evapotranspiration in the Qazvin Plain, a representative of the country's dry regions, during the statistical period of 1976 to 2005. Their comparison with the National Water Document revealed a 40.6% increase in annual potential evapotranspiration in the vineyard station (a sample station) in the Qazvin Plain. Consequently, the water requirements for plants in the region have also increased accordingly.

Arab Salghar et al. (2013) conducted a study on the changes in evapotranspiration and other climatic parameters at six synoptic stations in Iran. The findings indicated that in most of the stations, there has been an increase in maximum and minimum temperatures as well as evapotranspiration, while rainfall and relative humidity have decreased. In a 2013 study, Masoompour et al. investigated the temporal-spatial variability and the process of Evapotranspiration of the reference plant in Iran. The results indicated an increasing trend in evaporation-transpiration throughout the country. The largest annual trend change and evaporation-transpiration increase was observed in Birjand, Shahroud, Qazvin, Jask, Semnan, Babolsar, Dushan Tepe, and Sanandaj stations.

The least change was observed in the Fasa and Kish stations, where the amount of evapotranspiration remained almost unchanged. The highest change in the monthly trend occurred in July in the dry stations of the country, while the lowest change in the monthly trend occurred in December and January.

Yaghoobzadeh et al. (2016) studied the impact of climate change on evaporation-transpiration processes during the plant growth period in irrigated and rainfed fields. The results indicated an increase in daily reference evapotranspiration during the study period. Among the crops studied, wheat showed the largest change in evaporation-transpiration, with an increase of about 12%. Asadzadeh et al. (2016) also analyzed the evaporation-transpiration process of the reference plant using Spearman's test in the synoptic stations of Kurdistan province. The results revealed a significant and increasing annual trend of evaporation-transpiration for the Sanandaj station.

Nouri et al. (2016) investigated the changes in reference evapotranspiration (ET_o) during the 21st century in semi-arid regions of Iran. The results indicated that over the 21st century, ET_o (averaged across all stations) is projected to increase by 5.12%, 7.33%, and 11.01% during the initial, middle, and final 30-year periods, respectively, compared to the base period of 1966-1990. In a study conducted by Dolatshahi et al. (2017), the researchers investigated the trend of changes in climatic parameters and reference evapotranspiration (ET_o) in the vegetation area of North Zagros. The results indicated a significant upward trend in air temperature at the Piranshahr station for 24 years. Overall, the findings highlighted significant changes in the trend of some climatic parameters and ET_o in the vegetation area of North Zagros.

3.2. The process of changes in evapotranspiration for crops

The value of the Z-statistic obtained from the Mann-Kendall test for the process of changes in evapotranspiration of crops is presented in Table 4.

Table 4. Values of the Z statistic obtained from the Mann-Kendall test in plants

Plant	Z-Value	Plant	Z-Value
Sunflower	3.8^{***}	**Plum**	3.67^{***}
Leafy vegetables	3.36^{***}	**Pomegranate**	3.93^{***}
Potato	3.86^{***}	**Grape**	3.8^{***}
Apple	3.99^{***}	**Almonds**	3.43^{***}
Lentils	3.67^{***}	**Eggplant**	4.06^{***}
Walnut	3.99^{***}	**Cotton**	3.73^{***}
Pears	3.67^{***}	**Onion**	3.8^{***}
Wheat	3.85^{***}	**Barley**	3.92^{***}
Tomato	3.8^{***}	**Sugar beet**	3.93^{***}
Cherries	3.86^{***}	**Melon**	3.99^{***}
Peach	3.67^{***}	**Spring cucumber**	3.8^{***}
Watermelon	3.86^{***}	**Autumn cucumber**	3.8^{***}
Peas	3.67^{***}	**Fodder corn**	3.73^{***}
Vegetables	3.64^{***}	**Saffron**	3.64^{***}
Pistachio	3.86^{***}	**Cantaloupe**	3.8^{***}

*** is significant at the level of 0.1 percent.

The test results confirm increasing changes in the Evapotranspiration of crops in Kashmar Plain (Table 4). These findings align with the research of Shirmohammadi et al. (2018), who studied the spatial-temporal distribution of reference Evapotranspiration using CRU gridded data and predicted its changes in future periods in Khorasan Razavi province.

The spatial distribution of reference evapotranspiration values in Khorasan Razavi indicated that the annual value of this variable increases from north to south. Analysis of the time trend of this variable using two methods, least squares error and Man-Kendall, revealed a significant increasing trend in the annual value of this variable at all points of the investigated network.

Barzegari et al. (2015) conducted a study on the water needs of the agricultural sector in the Yazd-Ardakan Plain under climate change conditions. The results indicated significant changes in temperature and precipitation distribution in the area until 2030. The annual minimum and maximum temperatures are predicted to increase by 1.83 and 1.19 degrees Celsius, respectively.

The study also revealed that rising temperatures will lead to increased Evapotranspiration, resulting in up to a seven percent increase in the water requirement of plants due to climate change. In a separate study, Ahmadi et al. (2015) estimated and evaluated the annual reference evaporation-transpiration changes based on effective climatic parameters in Northeast Iran, showing an increasing trend of reference evaporation-transpiration in the region.

3.3 Comparison of transpiration-evaporation changes in plants compared to NETWAT software

The results indicate that the process of Evapotranspiration of plants in the cultivation pattern of the region increased during the 20 years from 1998 to 2017 (Table 5). It is important to highlight that saffron and cantaloupe, which are significant crops cultivated in this region, have not been analyzed using the NETWAT software. Therefore, only the calculated amounts in this study are presented in Table 5. As a result, the section of the table related to the NETWAT software amounts and the percentage increase for these two plants is left blank.

The results of this study indicated that the calculated values of evapotranspiration for the main plants in the cropping pattern—except for cantaloupe and saffron—are higher than those reported in the NETWAT software. On average, the evapotranspiration rates of these plants show an increase of 27.41% compared to the values in the NETWAT software. This difference can be attributed to the variations in meteorological parameters used for calculating the evapotranspiration of the reference plant. The current climatic conditions differ from those considered in the NETWAT software, which is based on data from previous years (before 1999). Specifically, the NETWAT software calculations were based on meteorological data from 1970 to 1995, whereas this study utilized data from 1998 to 2018.

Based on the climatic trends discussed earlier, it is evident that the rise in temperature and wind speed, along with the decline in relative humidity and sunny hours, has resulted in a significant increase in the evapotranspiration of the reference plant. This, in turn, has led to higher evapotranspiration values for the cultivated model plants.

Table 5. Evapotranspiration values of plants in the cultivation pattern

Plant	Evapotranspiration during the growth period (mm)		Percentage increase
	Software NETWAT	Calculated	
Sunflower	752	951	26.46
Plum	993	1235	24.42
Pomegranate	969	1162	19.94
Grape	741	908	22.58
Almonds	1162	1198	3.07
Eggplant	807	1062	31.55
Cotton	896	1190	32.83
Onion	893	1049	17.51
Barley	517	662	28.07
Sugar beet	1122	1588	41.51
Melon	694	916	32.06
Spring cucumber	725	962	32.75
Autumn cucumber	157	243	54.8
Fodder corn	723	994	37.5
Saffron	----	404	----
Leafy vegetables	836	1032	23.42
Vegetables	599	724	20.94
Potato	1081	1359	25.7
Apple	1008	1267	25.73
Lentils	696	839	20.54
Walnut	1010	1287	27.41
Pears	1041	1308	25.68
Wheat	583	727	24.71
Tomato	1037	1301	25.49
Cherries	952	1207	26.83
Peas	694	876	26.27
Peach	993	1235	24.42
Watermelon	701	894	27.56
Pistachio	675.2	931	38
Cantaloupe	----	724	----

Fig. 1 illustrates the correlation between the plant evapotranspiration values calculated in this study and those provided by the NETWAT software. The coefficient of determination is 0.93, indicating a strong correlation between the calculated values and the values obtained from the software.

Also, in Table 5, the highest increase is seen in autumn cucumber plants (54.8%), sugar beet (41.51%), and pistachio (38%), while almonds show the lowest increase at 3.07%. This increase is attributed to Evapotranspiration. After that, Pomegranate (19.94%) and lentils (20.54%) exhibit the lowest values for increased evaporation, transpiration, and water requirement. These findings align with previous research by Erfanian et al., (2009). They conducted a study to assess the changing irrigation needs of plants in Khorasan Razavi province compared to the data in the National Irrigation Document. The findings indicated that in most locations, there has been an increase in air temperature, a decrease in air humidity, a relative reduction in rainfall, and an increase in sunlight and wind speed. As a result, the water requirements for the reference plant and the main plants used in cultivation have increased. When considering the entire statistical period, the water requirement for the reference plant has increased by an average of 47%. When only the last 15 years are considered, this increase exceeds 48% in some parts of the province. Consequently, there is a need to revise and update the existing document. Mohammadi et al. (2012) conducted a study on the impact of temperature on the water needs of cotton plants in Sabzevar city from 1956 to 2010.

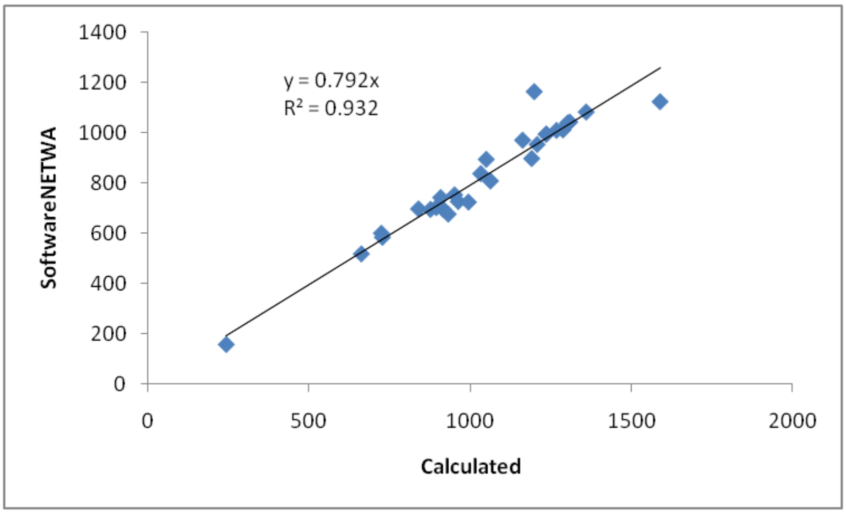

Fig 1. Correlation diagram between calculated evapotranspiration values and those presented in NETWAT software

The study revealed an increasing trend in Evapotranspiration over this period. Monthly analysis showed that the highest Evapotranspiration levels occurred in July and August, while the lowest levels were observed in January due to the lowest temperatures. Using the crop watt model, the average irrigation requirement for the cotton plants over the study period was 1371.8 mm. Statistical tests confirmed a significant increasing trend in water requirement at a 95% confidence level. Jafarzadeh et al. (2016) investigated the effects of climate change on the water requirement of saffron in South Khorasan province using GIS. The results showed that all the suitable areas of the province for saffron cultivation will face an increase in water demand in 2040.

Shabani et al. (2015) predicted changes in water requirements for various agricultural products in the Mashhad Plain due to fluctuations in air temperature. The study showed primarily, the changes in potential Evapotranspiration would be influenced by changes in maximum temperatures. Comparing water requirements for different crops between future and base periods revealed an increase in Evapotranspiration for plants in the future. Among the five selected crops in the Mashhad Plain, sugar beet exhibited the highest percentage increase in water requirement, at 8.82%, equivalent to 290 m^3 of water consumed per hectare.

Yaghoobzadeh et al. (2016) investigated the effect of climate change on the process of evaporation-transpiration changes during the growth period of plants in irrigated and rainfed fields. The results showed that wheat with about 12% change compared to corn with 3% change, will show the greatest change of evaporation-transpiration in the future periods compared to the base period during growth. Barati et al. (2017) in research by calculating the net irrigation requirement of plants in the Kermanshah plain cultivation pattern and comparing the obtained values with the values available in the NETWAT software, stated that the results of this research are on average 1.2 times the values presented in the software. The application is NETWAT. In a study conducted by Mehrazar et al. (2017), the effects of climate change on the agricultural sector of Hashtgerd Plain were investigated.

The results indicated that the irrigation water requirement for wheat, barley, corn, and alfalfa could increase by up to 16%, 17.21%, 26%, and 20% respectively under the influence of climate change. Additionally, the decrease in potential crop production and the increased need for irrigation water due to climate change will lead to a reduction in water productivity. The maximum decrease in water productivity is projected to be -26.5%, -35%, -38.5%, and -30.9% for wheat, barley, corn, and alfalfa, respectively.

4. Conclusion

In this research, using the Mann-Kendall test, the temporal changes of reference Evapotranspiration in the dry climate of the Kashmar plain were evaluated. The results showed that some climatic parameters have an increasing trend and some have a decreasing trend. At the same time, the trend of reference Evapotranspiration changes during the period under investigation is incremental. According to the results, among the climatic parameters investigated in all monthly, seasonal, and annual time scales, wind speed had the greatest effect in increasing the amount of reference Evapotranspiration. In the next step, the process of changes in Evapotranspiration of the cultivated plants in the Kashmar plain was also evaluated using the Mann-Kendall method.

The results showed that the process of changes in Evapotranspiration of plants increased causing an increase in the water requirement of plants in the region. A comparison of plant Evapotranspiration calculated in this research with the values of NETWAT software showed that the highest increase belongs to autumn cucumber plants (54.8% increase), sugar beet (41.51% increase), and pistachio (38% increase) and the lowest amount of increase is related to almonds with a 3.07% increase in Evapotranspiration. After that, pomegranate (19.94% increase) and lentils 20.54% increase have the lowest values of increased evapotranspiration and water requirement. Therefore, a new arrangement should be considered for optimal cultivation in terms of production, performance, and economy due to the increase in Evapotranspiration of plants and the consequent increase in the water requirement of plants. The revision of plants in the cultivation pattern, optimization of irrigation methods, and increase of irrigation efficiency are some of the achievements that could take. The results of this research can help to make decisions about the pattern of plant cultivation, the sustainable development of agriculture, and the economic prosperity in the region.

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6. Disclosure Statement

The authors reported no potential conflict of interest.

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