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Spatiotemporal changes of evaporation in Golestan province based on quantile regressions

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ABSTRACT

The results reveal statistically significant trends with distinct slopes in distinct quantiles for each station and season so that the changes in the trend of high values (quantile 0.9) of evaporation were more than low values (quantile 0.1). In the spring, medium and high evaporation rates increased in the northern regions of the province (the highest trend slope, 0.15 mm/decade in the northeast), while they fell (with a slope of −0.15 mm/decade) in the southern regions. But the high values of evaporation in summer have increased in most of the stations (the highest trend slope, 0.15 mm/decade). In contrast, high levels of evaporation in autumn and winter grew at a rapid rate in the eastern part of the province (the highest slope according to season, 0.15 and 0.2 mm/decade), but they declined in the western half (the highest slope, −0.1 and −0.15 mm/decade, respectively). In general, there was a significant decreasing trend for evaporation, mostly in the western half, but there was an increasing trend, mostly in the eastern half of the province. Significant increases in daily evaporation, particularly during the dry season, will diminish water supplies, destabilize the agricultural sector, and eventually desertify the area.

Key words: evaporation, extreme values, Golestan, quantile regression, spatiotemporal trends

HIGHLIGHTS

- The trend of evaporation pan was investigated by the quantile regression method.
- The amount of change in different quantiles of evaporation pan was estimated.
- The high values of evaporation increased in different seasons.
- The slope of the trend was different for different amounts of evaporation.

INTRODUCTION

Evaporation from water surfaces (pan evaporation) is a crucial component of the hydrological cycle, which is an important measure for evaluating atmospheric evaporative demand (Mozny *et al.* 2020). The evaporation parameter is a crucial component of the hydrological cycle, strongly associated with changes in the weather system. Understanding the geographical and temporal variations of evaporation and its modeling is crucial for agricultural activities, natural resource management, and water and soil conservation (Moosavi 2020). Evaporation rates vary from region to region based on climate, season, availability of surface water, and wind speed. Increasing greenhouse gases have altered patterns and changed the trend of extreme climatic variables (very high and very low values of climatic variables) that are crucial to agriculture, water resources, and environmental risks (Fathian *et al.* 2020). Recent decades have witnessed the occurrence of global warming (Adnan *et al.* 2020; Nasrollahi *et al.* 2021a).

Considering climate change, it can be seen that the temperature is increasing, and consequently, the evaporation rate is also increasing (Donohue *et al.* 2010). If the rainfall does not change and the temperature rises, then the annual average evaporation will increase and water productivity will decrease. However, along with climate change and global warming, due to the specific climatic conditions of Iran, which is generally dry and semi-arid with high evaporation potential, the occurrence of floods and droughts is a normal thing, also, with the increase in population and the ever-increasing development of factories, the need for water and the amount of consumption is increasing day by day. Therefore, the main problem is the correct management of water and how to store and supply it for the coming months and during the cropping seasons.

Also, in recent years, along with the reduction of available water resources in Golestan province, located in the northeast of Iran, the high amount of water evaporation and plant transpiration due to drought and the reduction of vegetation, indiscriminate water harvesting and low rainfall have created issues and problems in the supply of agricultural water and the management of water resources in this province. It is necessary to compile scientific and practical programs to reduce evaporation, especially in arid and semi-arid areas of the province. Therefore, to create better management conditions to reduce water loss due to changes in evaporation, in the first step, it is necessary to investigate the temporal and spatial changes of evaporation in the region, conducted in the form of trend analysis.

Several scholars have researched the trend changes of climatic and hydrological parameters in various locations of Iran, indicating an increase in temperature and a decrease in precipitation and discharge in northeastern Iran (Minaei & Irannezhad 2018; Mahmoudi *et al.* 2019; Javanshiri *et al.* 2021), an increase in minimum and maximum temperatures and a decrease in extreme precipitation in western, northern, and northwestern Iran (Fathian *et al.* 2020), an increase in minimum and maximum temperature, by 1.8 and 4.56 °C, respectively, in the future period (2041–2080) in the western regions of Golestan province (Silakhori *et al.* 2022), an increase in temperature, and decrease in rainfall and Groundwater level in the near future period (2020–2040) in the Tasuj plain in northwestern Iran (Ghazi *et al.* 2022), an increase in temperature and an decrease in monthly precipitation in the near future period (2015–2100) in Tabriz city, Northwest of Iran (Ghazi & Jeihouni 2022), an increasing trend of evapotranspiration in the west and northwest of Iran (Dinpashoh *et al.* 2019), as well as an increase in maximum wind speed and humidity (Ghaedi 2019; Asadi & Karami 2022). Likewise, Karimi *et al.* (2020) observed an increasing trend in wind speed, air temperature, and a drop in relative humidity in southern Iran, resulting in an upward trend needed for atmospheric evaporation, which shows a rise in drought severity and is mainly attributable to a greater need for atmospheric evaporation. Machekposhti *et al.* (2018) found a drop in precipitation and an increase in temperature and evaporation in western Iran. In addition, according to Bazzi *et al.* (2021), an analysis of projected changes in evaporation in southern Iran for the years 2080–2030 revealed an increase in evaporation, indicating climate change. The results of several researches indicate that Iran, like many other countries, is influenced by climate change, which has altered hydro-climatic variables such as temperature, evaporation, precipitation, runoff, and radiation (Moghim 2018).

At the global scale, several researches on evaporation variations attributed their causes to types of phenomena. Stephens *et al.* (2018) demonstrated that the evaporation trend in South/West Australia has decreased, primarily as a result of a reduction in wind speed. Hounguè *et al.* (2019) investigated the rainfall trends, temperature, evaporation, wind speed, relative humidity, and sunny hours in the Ouémé Delta in Benin from 1960 to 2016 using a combination of the Mann-Kendall test and indicated that rainfall increased significantly. The average pan evaporation in the region exhibited a considerable rising trend when the temperature rose rapidly. Variations in pan evaporation may be expressed by wind speed and sunny hours, and if temperatures rise in the future, pan evaporation may increase dramatically. Observations from the Czech Republic indicate an increasing trend in pan evaporation related to a decline in vapor pressure and an increase in global radiation (Mozny *et al.* 2020). From 1961 to 2017, Niu *et al.* (2021) estimated the evaporation from the pan (EVP) and its influencing variables in China. The results indicated that the impacts of Wind Speed (WIN), Sunny Hours Duration (SSD), and Vapor Pressure Deficit (VPD) were the primary causes of EVP variations throughout China. VPD, Relative humidity (RHU), WIN, and SSD were the most sensitive seasonal climate variables. Moreover, the Pacific Decimal Oscillation Index (PDO) demonstrated a significant negative correlation with EVP, whereas the El Nino 3.4 (N3.4) and East/West Russia (EA/WR) indices had a positive correlation in the majority of regions. Due to changes in the evaporation process around the world, particularly in Iran, the study of its temporal and spatial changes is crucial for the optimal management of water and soil resources in each region. Therefore decision-makers in water resources planning and management should have a comprehensive knowledge of spatio-temporal variations in evaporation processes.

Most of the evaporation trend studies conducted in Golestan province and also in Iran are limited to the investigation of changes in the average of the data, while the changes in the upper or lower percentiles (extreme values) and generally the different domains of the evaporation data have not been investigated, perhaps knowledge of the changes in the extreme values of evaporation is very important in management studies regarding climate hazards. In contrast to tests based on mean or median data, quantile regression methods (Mann 1945; Sen 1968; Kendall 1975; Pettitt 1979) can detect changes in different values of climatic and hydrological parameters, particularly extreme values. The quantile regression method, which provides the possibility of calculating and plotting regression curves or lines for each desired quantile (Bararkhanpour *et al.* 2020), is utilized in numerous meteorological fields, including the study of temperature changes (Gao & Franzke 2017; Salman *et al.* 2018; Pumo & Noto 2021; Yao *et al.* 2022), wind velocity (Gilliland & Keim 2018), relative humidity (Nian *et al.* 2022), water flow (Franco-Villoria *et al.* 2019), and precipitation (Wasko & Sharma 2014; Mohsenipour *et al.* 2020; Kalisa *et al.* 2021; Treppiedi *et al.* 2021). This method replaces the conditional mean function in ordinary linear regression with a conditional quantile function (Koenker & Bassett 1978; Koenker & Hallock 2001; Barbosa 2008) and estimates the regression lines for different quantiles (Reich 2012).

Applying the quantile regression method establishes a comprehensive relationship between explanatory variables and various components of the dependent variable (Benoit & van den Poel 2017; Zhang *et al.* 2020). One of its primary advantages is being insensitive to outliers without requiring a normal distribution of error. Additionally, this method permits variables with heterogeneous variances (Bararkhanpour *et al.* 2021). Dunn *et al.* (2019) examined worldwide variations in daily surface temperatures and wind speeds using the multiple regression approach and discovered an upward trend in high temperatures of summer in Eastern Europe and low temperatures of winter in the North. In the fall and winter, the northern regions of North America had significant temperature decreases. Kousali *et al.* (2022), who examined the seasonal and yearly variations in the volume of surface runoff discharge from the Ghara-su River to the Gulf of Gorgan, Iran, between 1971 and 2018, determined that the magnitude of changes in the upper quantiles was greater than the lower quantiles. This demonstrates the significance of evaluating the fluctuations of different quantiles rather than only the data's mean. The findings of the quantile regression approach applied to variations in high relative humidity during 2006–2006 in the Tarim Basin revealed that high relative humidity values, as well as the average value, grew considerably over the period (Nian *et al.* 2022). Shah *et al.* (2022) investigated the trends of extreme values of meteorological variables (precipitation, dew point temperature, air temperature, wind speed, and relative humidity) and the effect of atmospheric variations in central and southern Ontario, Canada. Extreme meteorological variables are more directly affected by local and regional humidity and heat balance processes than global atmospheric circulation variables, and the existence of trends in humidity, strong wind speeds, and air temperature indicate that it has a profound impact on the phenology of terrestrial and aquatic ecosystems. Despite the significance of investigating evaporation changes, no research has yet been undertaken on the temporal and geographical variations in evaporation different and extreme values in Iran's dry and semiarid regions. In this study, we will evaluate the pattern of variations in pan evaporation in the province of Golestan using the quantile regression method over the different seasons.

MATERIALS AND METHODS

Study area and data collection

With a total area of 20,367 km^2, Golestan province (Figure 1) in northern Iran was chosen as the study region and is located between 36 30°N and 38 8°N latitudes and 53 57°E and 56 22°E longitudes. This study area consists of the Alborz mountains, plains, and lowlands from south to north (Shamsipour & Rodgar Safari 2020). The gradient declines from north to south and east to west. Golestan, adjacent to the Turkman Sahra, has a semiarid and arid climate (Hosseinalizadeh *et al.* 2020; Raziei 2022). The province's Meteorological Organization provided the data for this study, which includes daily evaporation measurements from 12 synoptic stations over a period of 34 years between 1985 and 2018 in common.

Method

In the present study, a seasonal time series of evaporation data was first compiled for spring (March, April, and May), summer (August, July, and June), autumn (November, October, and September), and winter (December, January, and February) seasons. Quantile regression was then employed to examine the changes in evaporation at each quantile level. The slope of the trend was interpolated at various stations throughout the Golestan province.

Definition of quantiles

Quantiles are particular parts of a data set and determine how many values in a distribution are above or below a certain value. For the random variable y, the parameter μ_σ is the quantile of σ for $F(y)$ in the condition that the following inequality holds (Bararkhanpour *et al.* 2019):

$$P(y < \mu_\sigma) \le \sigma \le P(y \le \mu_\sigma), \qquad 0 < \sigma < 1 \tag{1}$$

$F(y)$ is the cumulative distribution function of the random variable y and $P(y)$ is the probability of occurrence.

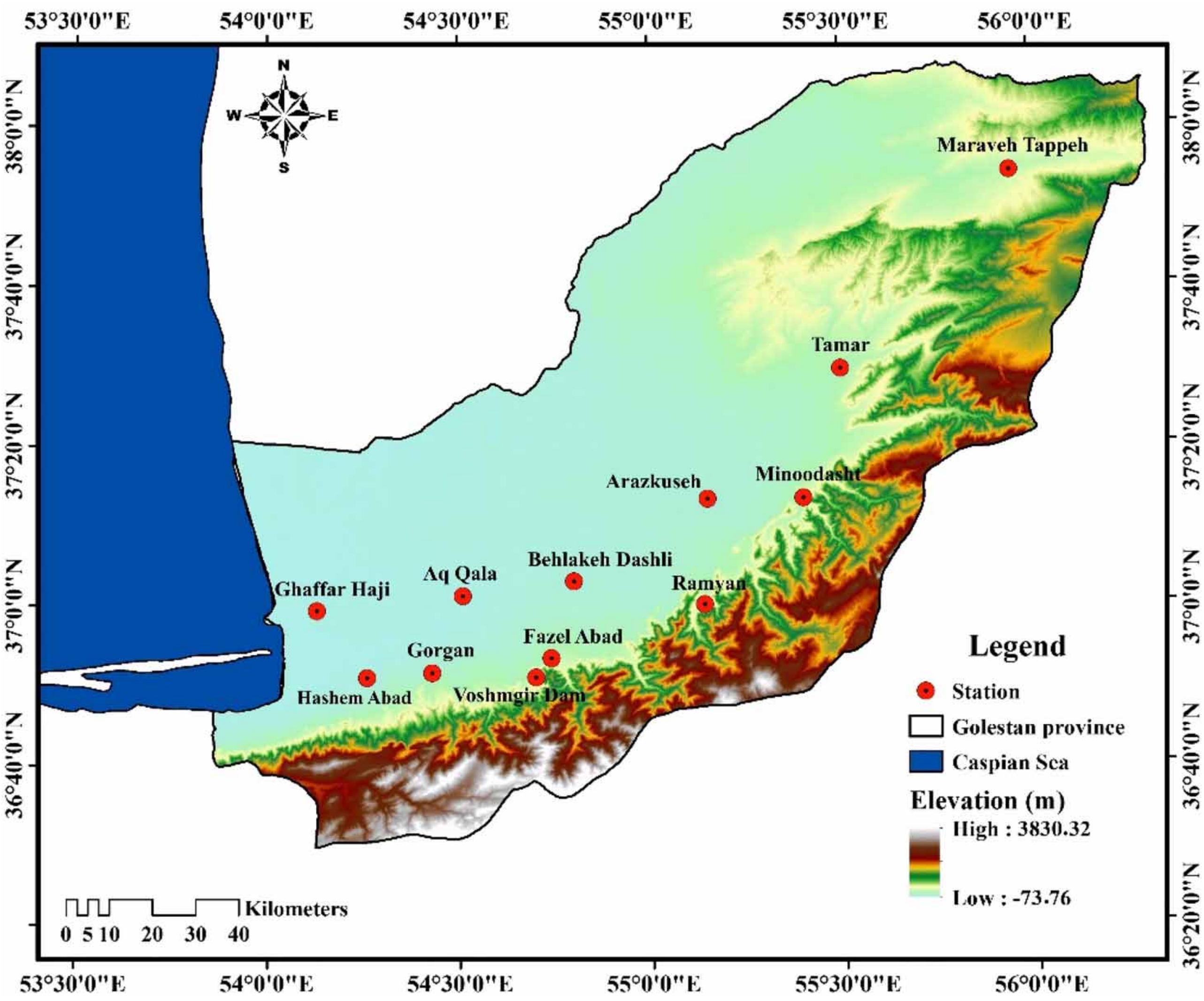

Figure 1 | Ggeographical location of the studied stations.

Quantile regression

The quantile regression method is a statistical technique for determining the percentile of climate variables during different time periods (Wu *et al.* 2021). In addition to examining the relationship between one or more independent variables and a dependent variable, this technique has been extensively employed for trend analysis (Cannon 2018; Kalisa *et al.* 2021; Pumo & Noto 2021). This statistical method provides additional information on the changes of different values of a variable, particularly extreme values, and is typically employed to model different quantiles of the dependent or response variable on the independent variable(s) or on time. In addition, it permits us to investigate the statistical relationship between the dependent variable and independent variable(s) across the entire data distribution (Bilal *et al.* 2021). The quantile regression method was proposed by Koenker & Bassett (1978) and is as follows:

$$(\sigma|x) = \beta_0(\sigma) + \beta_1(\sigma)x + \theta \tag{2}$$

where $\beta_0(\sigma)$ is the line intercept and $\beta_1(\sigma)$ is the slope of regression, both of which change depending on the σth value of the quantile of interest; θ is the error and σ ranges from 0 to 1 (Lee *et al.* 2013). Unlike the linear regression model, which is based on reducing the square of the residuals of the model, the quantile regression approach employs the minimization of the Least

Absolute Deviation (LAD) of the model residuals, to estimate quantile regression:

$$minimize\left\{\sum_{\{i|y_i<y_\sigma(x_i)\}}(1-\sigma)|y_i-y_\sigma(x_i)|+\sum_{\{i|y_i\rangle y_\sigma(x_i)\}}\sigma|y_i-y_\sigma(x_i)|\right\} \tag{3}$$

To fit the quantile regression, the approach of minimizing the sum of the absolute values of the residuals is used. Where $y_\sigma(x_i)=\beta_0(\sigma)+\beta_1(\sigma)x_i$ and i = 1,2,…, n. β_σ parameters are calculated from Equation (4) (Koenker 2005):

$$\hat{\beta}_\sigma = argmin\sum_{i=1}^{n}\rho_\sigma(y_i-x_i^T\beta) \tag{4}$$

where the function $\rho_\sigma(.)$ is defined as Equation (5) (Koenker 2005):

$$\rho_\sigma(u)=\left\{\begin{array}{ll} u(\sigma-1) & if \quad u<0 \\ u\sigma & if\ u\geq 0 \end{array}\right\} \tag{5}$$

The R's software's quantreg package (Koenker 2022) was utilized to implement quantile regression. The interested reader is referred to Koenker & D'Orey (1987), Koenker (2005) and Koenker (2010) for additional information.

RESULTS

The quantile regression approach was used for the daily evaporation values in different seasons for 12 selected stations in Golestan province based on several quantiles (0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, and 0.99). Figure 2 depicts the slopes of trend lines for different quantiles of evaporation parameter (each line shows the slope of the trend line for the considered quantile) at three representative stations including Aq Qala (western Golestan area), Ramian (southern Golestan region), and Maraveh Tappeh (eastern Golestan region) stations throughout different seasons.

Different trend slopes were observed for various quantiles and were different from the mean regression slope (ordinary linear regression), indicating that the strength of the changing trend varied for various evaporation parameter values. The slope of the trend lines for extreme upper quantiles (0.90, 0.95, and 0.99) is often substantially steeper than for extreme lower quantiles (0.01, 0.05, and 0.1). Therefore, it may be stated that high evaporation rates have undergone more significant changes during the past few decades. Autumn and winter had the steepest trend slope at the Aq Qala station, with a declining and negative trend slope. At Ramyan station, an upward trend was noted for evaporation, particularly for high evaporation rates (higher extreme quantiles). At the Maraveh Tappeh station, however, the lower quantile lines (less than 0.5) in summer and the higher quantile lines (greater than 0.5) in autumn exhibited an upward trend, but a decreasing trend in spring and winter. Also, the distance between the quantile regression lines for the evaporation data distribution in autumn and winter for Aq Qala station in the early years is greater than in the last years, which shows that the evaporation data distribution in these two seasons had a positive skewness, while the seasonal evaporation data distribution (for different seasons) in Ramian station and also the evaporation data distribution in the autumn season for Maraveh Tappeh station have negative skewness.

Table 1 illustrates the daily evaporation values connected to each target quantile and the value of seasonal incremental or decreasing variations over the examined years for the three stations of Aq Qala, Ramyan, and Maraveh Tappeh. For Aq Qala station, evaporation is decreasing in most quantiles and notably in fall and winter. In several quantiles, the decreasing changes were more than 100%. For example, the 0.01 quantiles in spring are equal to 0.4, which is lowered by 0.6 mm. Also, in the fall, all evaporation quantiles drastically dropped. Most of the evaporation variations in fall and winter are due to abnormally high quantiles which suggest substantial evaporation. The 0.99 evaporation quantile in this season, equal to 8.7- and 5.3-mm daily evaporation, witnessed a considerable reduction of 5.5 and 5.7 mm, respectively. But for Ramian station and unlike Aq Qala, changes in evaporation trend have been positive and substantial in all seasons and most quantiles. The biggest incremental increases in evaporation occur in summer and autumn in the middle and upper quantiles, such that the highest rise in summer evaporation in the upper quantiles of 0.9 and 0.95 was equivalent to 11.3, and 13 mm by 5.22 and 5.33 mm, respectively. But in the fall, the evaporation values of 7.8 and 11 mm (corresponding to 0.95

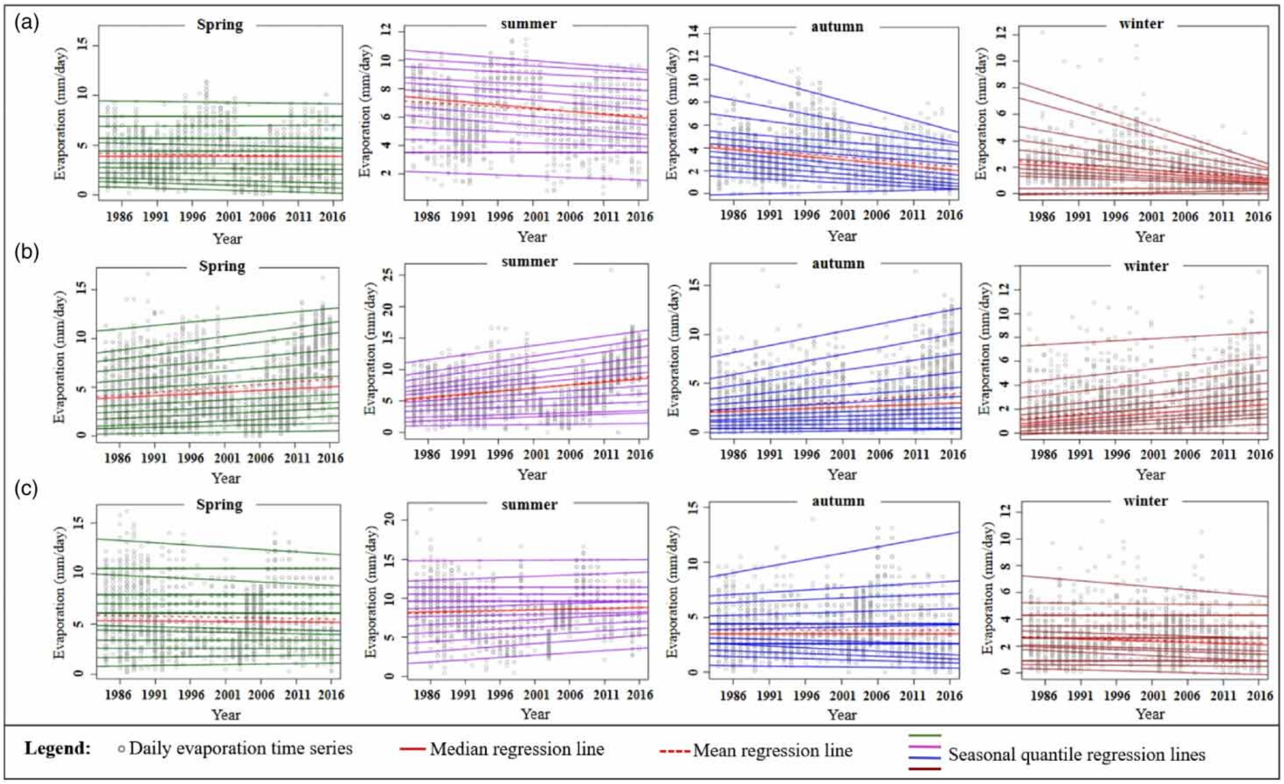

Figure 2 | Quantile regression lines slope (from bottom to top including 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, 0.99) on the seasonal trend of daily evaporation in (a) Aq Qala, (b) Ramian, (c) Maraveh Tappeh stations.

and 0.99 quantiles), rose dramatically by 4.4 and 4.6 mm, respectively. However, at Maraveh Tappeh station, evaporation changes were decreasing in all lower quantiles in autumn, while in most quantiles in spring and higher extreme quantiles in October the trend was positive and statistically significant. Most increases in evaporation in the higher quantiles were in spring and autumn, where evaporation values of 7.8 and 10.5 mm in fall rose by 1.2 and 3.8 mm, respectively. The evaporation rate of 4 mm (equal to 0.05 quantile) in summer increased by 2.2 mm, whereas the quantity of daily evaporation of 12.2 mm in spring fell by 1.4 mm.

The trend slopes and 90% confidence intervals of the slopes for the different quantiles and averages of daily evaporation in different seasons for three representative stations of Aq Qala, Ramian, and Maraveh Tappeh are illustrated in Figure 3. According to the figure, it can be stated that the slope of the trend in different quantiles is noticeably different from the mean regression slope, especially in the extreme upper and lower quantiles (quantiles >0.9 and <0.1, respectively); Therefore, it is possible to use the quantile regression approach to investigate the trend of different values of meteorological variables, especially extreme values, which are very important in the study of climate hazards because they provide more information on how changes occur in the distribution of meteorological and evaporation parameters.

At the Aq Qala station (Figure 3(a)), the slope values of trend in all four seasons are negative for most of the quantiles. In spring, the slope values in different quantiles are close to the mean regression slope. But in summer, the trend slopes in the middle quantiles (0.3–0.7) are greater than the extreme upper and lower quantiles, which shows that the middle values of daily evaporation have decreased with a higher intensity ($= > 0.04$) compared to very high and low values. In the autumn and winter, the slope values of the trend in the extreme upper quantiles (>0.85) are higher than the other quantiles, which indicates a noticeable decrease in the high daily evaporation values of Aq Qala station in this season. In the Ramian station (Figure 3(b)), the trend slopes in all quantiles are positive and increasing, so the highest trend slopes are for extreme upper quantiles or high values of daily evaporation. However, the slope of the trend for the upper quantiles of evaporation was higher in autumn (up to 0.15) and lower in winter (up to 0.06). Also, the slopes of the seasonal trend in all quantiles have a different value from the mean regression slope, while in the Maraveh Tappeh station (Figure 3(c)), the

Table 1 | Seasonal changes in daily evaporation for different quantiles in the target stations

			quantile								
Station	**Season**	**Evaporation changes (mm)**	**0.01**	**0.05**	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**	**0.95**	**0.99**
Aq Qala	Spring	Quantile equivalent evaporation	0.4	1	1.4	2.6	3.9	5.2	7	7.9	9.2
		Evaporation change	−0.6*	−0.61*	−0.48*	−0.18*	0	−0.46*	0.1	0	−0.3
	Summer	Quantile equivalent evaporation	1.8	3.5	4.2	5.2	6.6	8.3	9.2	9.7	10
		Evaporation change	−0.6	0	−0.47	−1.3*	−1.4*	−1.2*	−0.84*	−0.9*	−1.3*
	Autumn	Quantile equivalent evaporation	0.07	0.8	1.2	2	3.1	4.4	5.6	6.5	8.7
		Evaporation change	0.46*	−1*	−1.3*	−1.9*	−1.9*	−1.8*	−2.56*	−3.84*	−5.5*
	Winter	Quantile equivalent evaporation	0	0	0.4	0.9	1.6	2.6	3.5	4.7	5.3
		Evaporation change	0	0	0	−0.74	−1.2*	−2*	−3*	−5*	−5.7*
Ramyan	Spring	Quantile equivalent evaporation	0.4	1	1.4	2.6	4.4	7	9.2	10.4	12.5
		Evaporation change	0.32*	0.53*	0.98*	1*	1.2*	2*	2.7*	3*	2.2*
	Summer	Quantile equivalent evaporation	1.2	2.5	2.8	4.4	6.9	8.7	11.3	13	15
		Evaporation change	0.4	1.3*	1.1*	1.9*	3*	3.8*	5.22*	5.33*	4.8*
	Autumn	Quantile equivalent evaporation	0.1	0.4	0.8	1.4	2.6	4.2	6.1	7.8	11
		Evaporation change	0.33*	0	0.3*	0.7*	0.9*	1.7*	3.3*	4.4*	4.6*
	Winter	Quantile equivalent evaporation	0	0	0.2	0.9	1.6	2.6	4.3	5.3	7.9
		Evaporation change	0	0	0.8*	1*	1.5*	1.8*	2*	2*	1
Maraveh Tappeh	Spring	Quantile equivalent evaporation	0.9	1.8	2.6	3.5	5.2	7.5	9.6	10.5	12.2
		Evaporation change	0.3	−0.27*	−0.03*	−0.45*	−0.16*	0	−1*	0	−1.4*
	Summer	Quantile equivalent evaporation	2.6	4	5.2	6.9	8.7	10	11.4	13.1	14.9
		Evaporation change	1.9*	2.2*	1.8*	1.45*	0.58*	0	0	1.07*	0.13*
	Autumn	Quantile equivalent evaporation	0.5	1	1.6	2.6	3.5	5.2	6.9	7.8	10.5
		Evaporation change	−0.23	−0.61*	−0.8*	0	0	0	0.83*	1.2*	3.8*
	Winter	Quantile equivalent evaporation	0	0.6	0.9	1.6	2.3	3.3	4.3	5.2	6.5
		Evaporation change	− 0.44*	− 0.12	0	− 0.6*	− 0.53*	− 0.52*	0	− 0.16	−1.44*

Significance level: $P < 0.05$*.

slope values of the trend in different quantiles are more non-uniform and closer to the mean regression slope compared to the other two stations. In the spring and winter, there is a decreasing trend of evaporation with a negative slope in most of the quantiles, but in the summer, the extreme lower quantiles have a positive slope (slope values <0.05), and towards the upper quantiles, the slope values of the trend have decreased. Therefore, it can be stated that the low values of daily evaporation in summer have increased with a higher intensity than the high values. However, the lower quantiles of evaporation (<0.5) in the autumn have a negative slope, but the upper quantiles of evaporation (>0.6) have a positive and increasing slope; so the value of the positive slopes is higher in the extreme upper quantiles (>0.95).

The estimated slopes in autumn and winter for Aq Qala and Ramian stations have lower uncertainty (smaller uncertainty bands) compared to spring and summer. Also, the confidence intervals of the trend slopes for different quantiles in all studied stations have shown that, in general, the estimated trend slopes in winter and summer, as well as in lower quantiles, have higher certainty (smaller uncertainty bands) compared to the spring and autumn seasons.

Using GIS software, we investigated the distribution of trend slopes in 12 examined stations for the lowest (0.1), middle (0.5), and higher (0.9) quantiles; the findings are depicted in Figures 4–7. The results indicated that the trend of evaporation changes is substantial in the majority of cases and that the severity of growing and lowering trend slopes varies between areas of Golestan province and quantiles.

In the spring (Figure 4), the lower quantile of evaporation (0.1) in most stations has a significant decreasing trend (with a trend slope of −0.5 mm/decade), and only in three stations of Ghaffar Haji, Ramian, and Tamar have a significant increasing trend with a slope of 0.5 mm/decade. Therefore, it can be indicated that the low values of daily evaporation in Golestan province have changed significantly by (−0.5) – 0.5 mm/decade. But for the median quantile (0.5), the trend slopes are insignificant in most stations in the western half of the province. However, there is a noticeable and significant increasing trend (with a slope of 1.5 mm/decade) for the median value of evaporation in the Tamar station and significant increasing trends with a slope of 1 mm/decade for the Ramyan and Ghaffar Haji stations, while the stations in the central part of the province (Minoodasht, Arazkuseh, Fazel Abad, and Voshmgir Dam) have a decreasing and significant trend, which shows

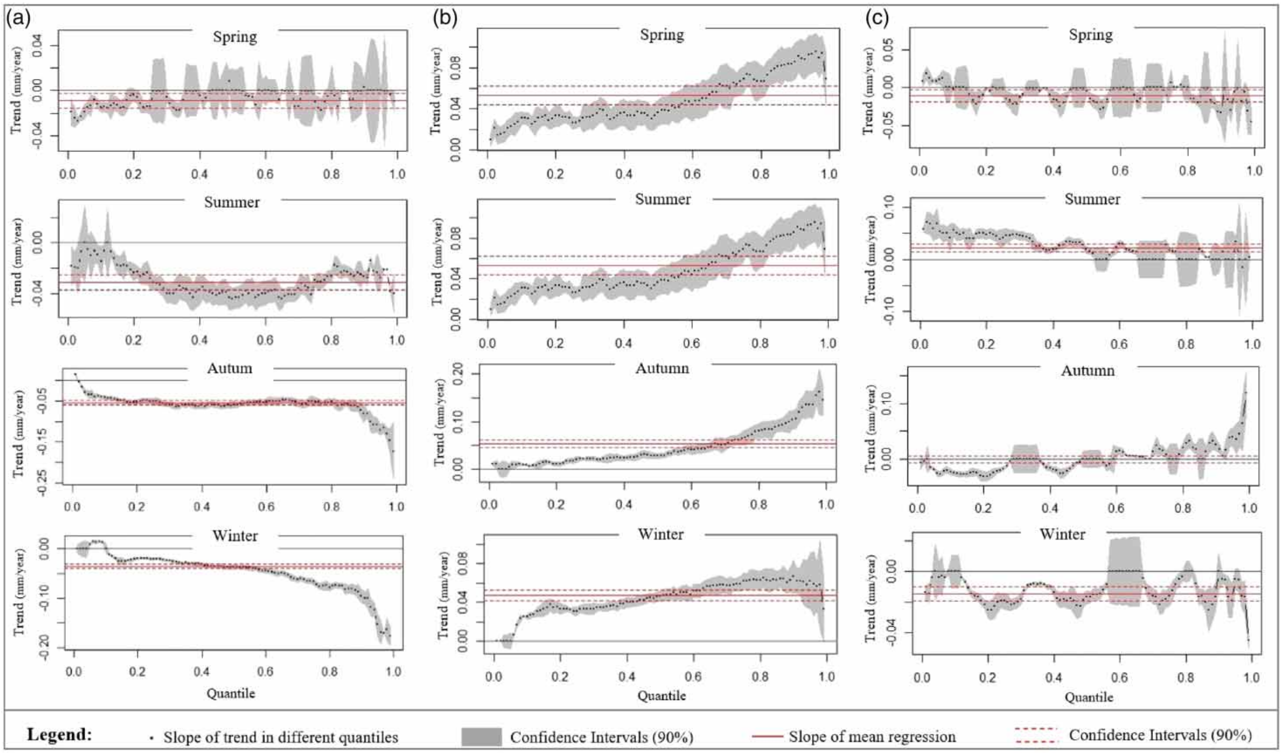

Figure 3 | Trend slope graph of daily evaporation time series in different seasons for (a) Aq Qala, (b) Ramian and (c) Maraveh Tappeh (The estimated slopes are for quantiles 0.01–0.99 with a step of 0.01).

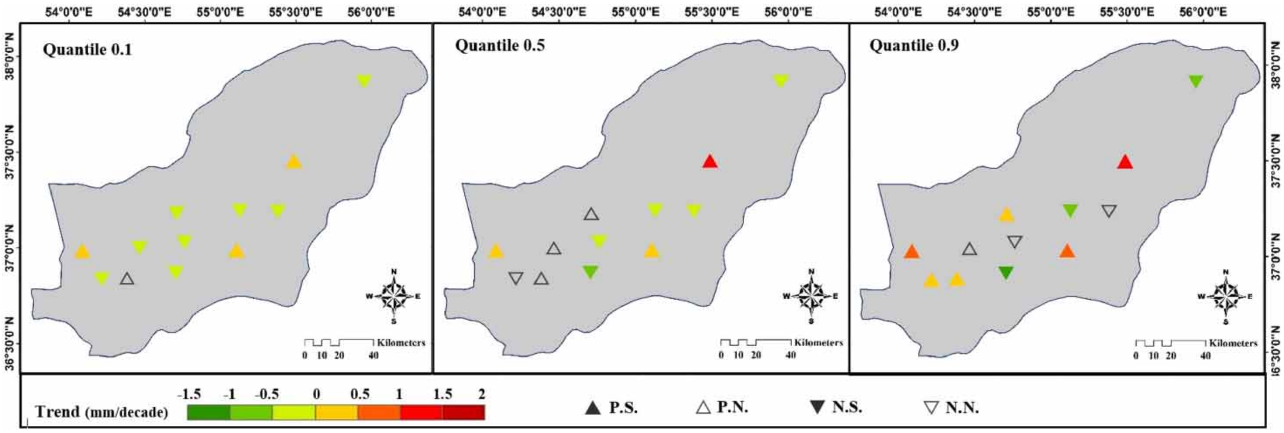

Figure 4 | Results of trend slope interpolation estimated by multiple quantile regression method for daily evaporation parameter in spring (P.S. and N.S. respectively represent significantly positive and negative trend at 0.05 significant level, whereas P.N. and N.N. correspond to P.S. and N.S. but for insignificant trend).

that the median value of daily evaporation has decreased in these areas, as the intensity of the decreasing trend has been higher at the Voshmgir Dam station (−1 mm/decade). For the upper quantile of evaporation in the spring season (Figure 4, right), there is a significant increasing trend for high values of daily evaporation in Tamar station (1–1.5 mm/decade), Ramyan and Ghaffar Haji stations (0.5–1 mm/decade) and Behlakeh Dashli, Gorgan and Hashem Abad stations (0–0.5 mm/decade). In general, the slope values of the trend for increasing and decreasing trends in high values of daily evaporation (quantile 0.9) have been relatively higher compared to the median and lower two quantiles.

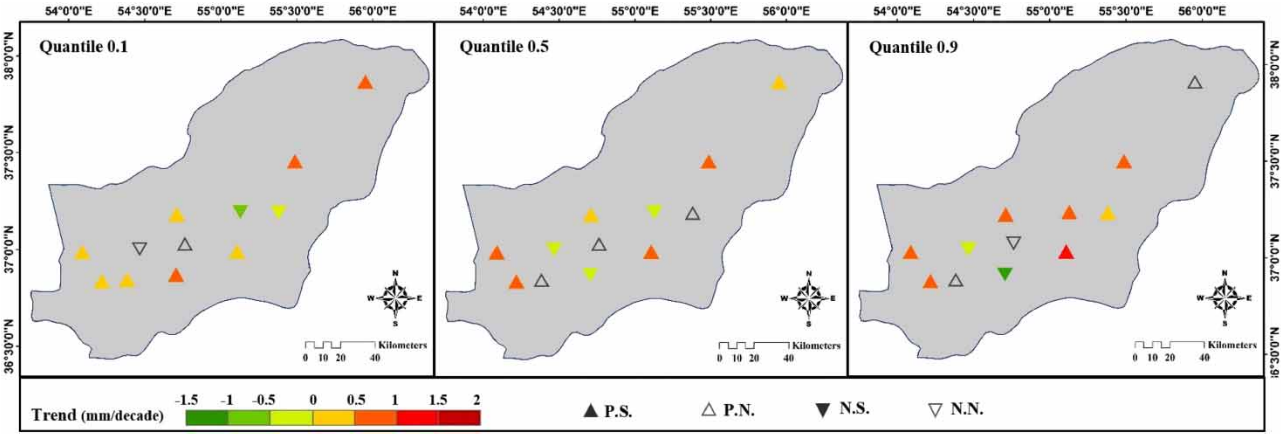

Figure 5 | Results of trend slope interpolation estimated by multiple quantile regression method for daily evaporation parameter in summer (P.S. and N.S. respectively represent significantly positive and negative trend at 0.05 significant level, whereas P.N. and N.N. correspond to P.S. and N.S. but for insignificant trend).

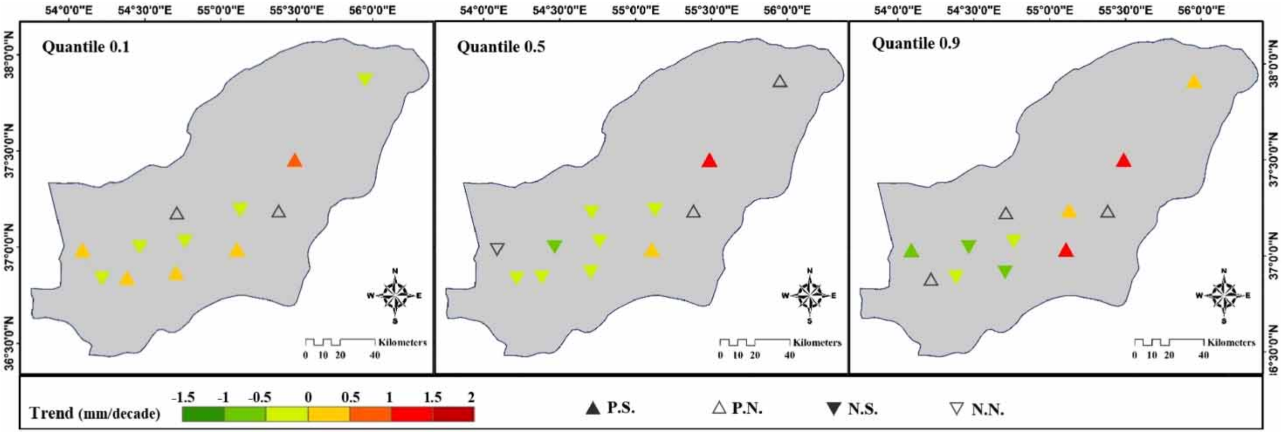

Figure 6 | Results of trend slope interpolation estimated by multiple quantile regression method for daily evaporation parameter in autumn (P.S. and N.S. respectively represent significantly positive and negative trend at 0.05 significant level, whereas P.N. and N.N. correspond to P.S. and N.S. but for insignificant trend).

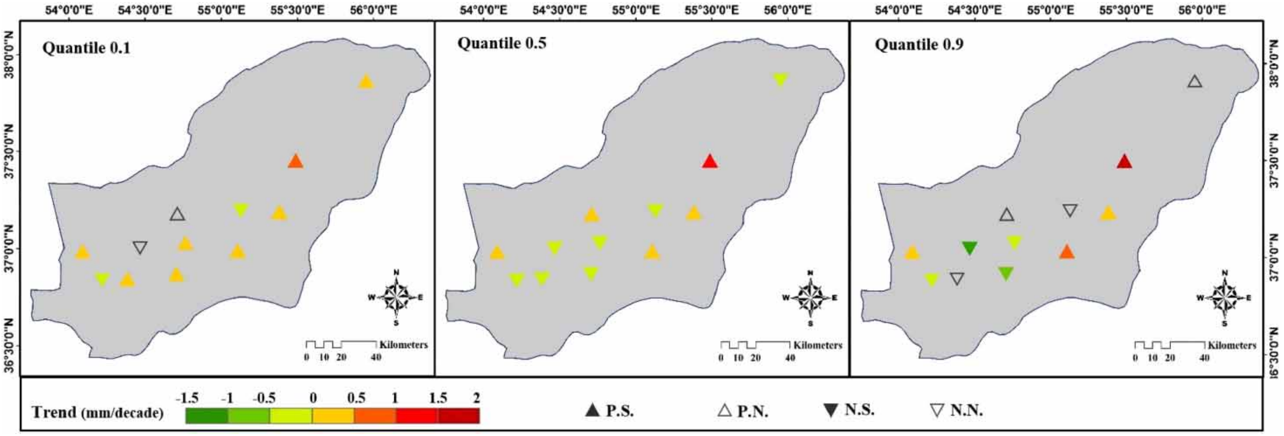

Figure 7 | Results of trend slope interpolation estimated by multiple quantile regression method for daily evaporation parameter in winter (P.S. and N.S. respectively represent significantly positive and negative trend at 0.05 significant level, whereas P.N. and N.N. correspond to P.S. and N.S. but for insignificant trend).

In the summer season (Figure 5), low values of daily evaporation (quantile 0.1) in most stations have a significant increasing trend (with a slope of 0.5 and 1 mm/decade) but have decreased in the Arazkuseh and Minoodasht stations with a slope value of −0.5 and −1 mm/decade, respectively. However, the low values of evaporation in the Aq Qala and Fazel Abad stations had a non-significant decreasing and increasing trend, respectively. For the median quantile of evaporation (0.5), the results show the presence of a significant increasing trend in Tamar, Ramyan, Ghaffar Haji, and Hashem Abad stations (with a positive slope of 1 mm/decade) and Maraveh Tappeh and Behlakeh Dashli stations (with a slope of 0.5 mm/decade). Therefore, it can be stated that the median values of daily evaporation in these stations have increased significantly during the statistical period of 34 years, while the median values of evaporation in Arazkuseh, Aq Qala, and Voshmgir Dam stations had a significant decreasing trend (0.5 mm/decade). Also, the high values of daily evaporation (quantile 0.9) in most of the studied stations located in the central and western regions of the province had a significantly increasing trend, and the intensity of the trend slope has been more in Ramyan station (1.5 mm/decade). However, there are significant decreasing trends in Voshmgir Dam and Aq Qala stations for high values of daily evaporation with a slope of −1 and −0.5 mm/decade, respectively but in other stations, trends were insignificant. In general, the results have shown that the slope values of the increasing trends of evaporation in the summer season were higher than in the spring season.

In the autumn and winter seasons (Figures 6 and 7), the significant increasing trends compared to the summer season were relatively less. The low values of daily evaporation in the autumn season (Figure 6) have a significant increasing trend in the Tamar (with a slope of 1 mm/decade), Ramyan, Voshmgir Dam, Gorgan, and Ghaffar Haji (0.5 mm/decade) stations and has a significant decreasing trend in Maraveh Tappeh, Arazkuseh, Fazel Abad, Aq Qala and Hashem Abad stations (−0.5 mm/decade), while the slopes of the increasing trend in two Minoodasht and Behlakeh Dashli stations were insignificant. Also, the median values of daily evaporation in the autumn season have decreased significantly in most of the studied stations, and the intensity of the slope of the negative trend was higher in the Aq Qala station (−1 mm/decade). However, there is a significant increasing trend in the Tamar and Ramyan stations (with a slope of 1.5 and 0.5 mm, respectively). There is a significant increasing trend in the Tamar and Ramyan stations (with a slope of 1.5 and 0.5 mm/decade, respectively). While the high values of daily evaporation in the stations of the eastern part of the province (Maraveh Tappeh, Tamar, Arazkuseh, and Ramyan) with the slopes of 0.5 and 1 mm/decade increased significantly, but the stations of the western half of the province (Fazel Abad, Voshmgir Dam, Aq Qala, Gorgan, and Ghaffar Haji) have decreased significantly with slopes of −0.5 and −1 mm/decade.

The low values of evaporation (quantile 0.1) in the winter season (Figure 7) have a significantly increasing trend in most of the stations, and the intensity of the trend slope is higher in Tamar station (1 mm/decade). A significant decreasing trend is also visible for the two stations of Arazkuseh and Hashem Abad (−0.5 mm/decade). However, for the median values of daily evaporation, the slopes of the trend were significant in all stations. So, the median evaporation values in Tamar (with a slope of 1.5 mm/decade), Minoodasht, Ramyan, Behlakeh Dashli, and Ghaffar Haji (0.5 mm/decade) increased significantly, but it has decreased in other stations. For the upper quantile (0.9) of evaporation in winter, the results have shown that the high values of evaporation in Tamar and Ramyan stations have increased with a trend slope of 2 and 1 mm/decade, respectively, and in Minoodasht and Ghafar Haji stations with a trend slope of 0.5 mm/decade, significantly. The high values of evaporation in Fazel Abad, Voshmgir Dam, Aq Qala, and Hashem Abad stations (with the slope of −0.5, −1, −1.5, and −0.5 mm/decade, respectively) have decreased significantly. However, the trend slopes in other stations were not significant.

DISCUSSION

According to the data, it can be stated that in most stations, there were substantially decreasing or increasing evaporation patterns. The increases in the top extreme evaporation quantiles showed a greater rate of change, indicating significant changes in very high evaporation rates. Different values (low, middle, and high) of evaporation in most studied stations had significant trends during different seasons. The most significant increasing trends were in the stations located in the eastern half of the province, while the most significant decreasing trends were observed in the eastern half of the Golestan province. The trend slope values for high values of evaporation are higher than middle and low values. The highest positive trend slope for different values of evaporation, especially high values were in autumn and winter seasons and at Tamar station (trend slope 2 mm/decade, 7 mm during 34 years), but in the summer season, it was at Ramyan station (slope 1.5 mm/decade, 5 mm during 34 years). However, the highest slope of the negative trend for high amounts of daily evaporation was at the Gorgan dam station (−1.5 mm/decade) for the spring and summer seasons, and at the Aq Qala station (−1.5 mm/decade) for winter. In the rest of the stations, the slopes of the trend in different seasons were smaller (1 and −1 mm/decade). However, the high values of evaporation have a non-significant trend in Minodasht, Fazel Abad, and Aq Qala stations in the spring season, Maraveh Tappeh, Fazel Abad, and Gorgan stations in the summer season, Minodasht, Behlakeh Dashli, and Hashem Abad stations in the autumn season and Minodasht, Behlakeh Dashli, Arazkuse and Gorgan stations in the winter season, and in general, the least significant trends for different values of evaporation were in Minodasht, Behlakeh Dashli, and Gorgan stations. Also, the intensity of increasing trends in the summer season has been higher than in other seasons. Therefore, since the most rainfall in the province occurs in the cold seasons of the year, it is expected that the hot periods of the year (spring and summer) will reduce the water resources due to the high temperature, and we will experience hotter and drier summers and springs than in the past decades. On the other hand, the results showed that the reduction of evaporation occurs in the cold seasons of the year, and if this reduction of evaporation is accompanied by an increase in rainfall, it is expected that the cold periods of the year will be wetter than in the past. In the stations that had a decreasing trend in the rate of evaporation, if the negative pattern of evaporation continues in these stations, the soil moisture in agriculture may have better conditions. On the other hand, the increasing trends of evaporation can increase evapotranspiration and the plant water requirement, which will lead to a more critical situation in the aquifers with excessive harvesting in the province. Although few studies have been conducted on the trend analysis of extreme values of evaporation in Golestan province, various researchers have shown that the average evaporation has increased in Golestan province and the northeast of Iran during various seasons (Shadmani *et al.* 2012; Moghim 2018; Soroush *et al.* 2020; Nasrollahi *et al.* 2021b).

Given that the eastern sections of the province are dry and semi-dry, a major rise in evaporation in these regions might sound the alarm for water shortage in warmer months of the year and especially for the agriculture sector. Rising temperature, insufficient rainfall, decreasing humidity, and increasing wind speed (Minaei & Irannezhad 2018; Baaghideh *et al.* 2020; Silakhori *et al.* 2022; Solaimani & Bararkhanpour 2022) are the most important reasons for the increase in evaporation in Golestan province, which has destroyed surface and groundwater resources. Various studies also noted a considerable rise in evapotranspiration in most regions of Iran, notably in the northeast, west, and northwest, which was largely due to higher wind speed and temperature, and a reduction in relative humidity. Nouri *et al.* (2018), Nasrollahi *et al.* (2021b) and Arpe *et al.* (2020) found a major change in strong wind speed over time in the southern Caspian Sea in 1995, resulting in enhanced evaporation after 1995.

In the context of investigating the factors affecting the changes in pan evaporation in Iran, and especially in Golestan province, Bararkhanpour *et al.* (2021) investigated the factors affecting the changes in different amounts of daily pan evaporation in Golestan province using quantile regression methods. For this purpose, they used the daily evaporation data and the factors affecting it, including the daily time series of average air temperature, relative humidity, sunshine hour, and wind speed for a statistical period of more than 30 years (1984–2016) and on a seasonal scale. The results showed that the parameters of average air temperature and wind speed have a positive effect on the evaporation parameter in spring, autumn, and winter seasons, and the effect value is much higher in the higher quantiles (>0.95). On the other hand, the relative humidity parameter has a negative decreasing effect in all evaporation quantiles. However, for the summer season, the results have shown the negative effects of high-temperature values (extreme temperatures) and the positive effects of high relative humidity values on evaporation in the eastern half of the province. Also, Soroush *et al.* (2020) investigated the spatio-temporal trend of pan evaporation and climatic variables related to evaporation and showed that there was a noticeable and significant increasing trend in the northern half of Iran. Also, the minimum, maximum, and average temperature as well as the sunshine duration were the most dominant variables affecting pan evaporation in spring, autumn, and summer, respectively.

As the evaporation tendency continues to worsen, the desertification of Golestan province is nothing of a surprise. Therefore, it is vital to think of particular methods for water usage and management. The results of this study will be useful in agriculture, water resource management, and adaptation against climate change (Ruiz-Alvarez *et al.* 2019). Our results can give valuable information about the region's climate and it will also assist to develop better management methods and planning for the region's restricted water resources (Mirdashtvan *et al.* 2020).

CONCLUSION

The quantile regression approach was employed in the current study to investigate the spatio-temporal trend of changes in different values of pan evaporation in Golestan province from 1985 to 2018 and on a seasonal scale. The trend of changes in various evaporation quantiles was analyzed, and the slopes of the trend were extrapolated in a GIS context. The most significant results are as follows:

- The slopes of most extreme upper and lower quantiles differed from the slopes of median and mean regression; hence, median and mean regression methods cannot be utilized alone to assess changes of trend in different ranges of the data time series.
- The trend of different values of evaporation in Golestan province is noticeably different in time and place, indicating that changes in the trend of evaporation can have different effects on the area. Therefore, the results of this study emphasize the need to further analyze the effects of climate change on extreme evaporation values, especially in arid and semi-arid climates.
- Different amounts of evaporation in summer have increased more severely. The highest positive slope of the trend in the high values of evaporation is seen at Tamar (spring, autumn, and winter) and Ramyan (summer) stations but the highest negative slope of the trend in Gorgan Dam (Spring and Summer) and Aghala (winter) Stations. In general, there were the most significant increasing trends in the stations of the eastern half and the most significant decreasing trend in the western half of the province.
- Increased evaporation and decreased precipitation in Golestan province threaten water resources, and plant cover, and cause desertification, which, if not handled effectively, may cause permanent harm to water resources and agriculture, particularly during dry seasons. To combat the phenomena of water evaporation, it is required to identify its core causes and provide scientific and practical remedies.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Adnan, S., Ullah, K. & Ahmed, R. 2020 Variability in meteorological parameters and their impact on evapotranspiration in a humid zone of Pakistan. *Meteorological Applications* **27** (1), 1–10. https://doi.org/10.1002/met.1859.

Arpe, K., Molavi-Arabshahi, M. & Leroy, S. A. G. 2020 Wind variability over the Caspian Sea, its impact on Caspian Seawater level and link with ENSO. *International Journal of Climatology* **40** (14), 6039–6054. https://doi.org/10.1002/joc.6564.

Asadi, M. & Karami, M. 2022 Modeling of relative humidity trends in Iran. *Modeling Earth Systems and Environment* **8** (1), 1035–1045. https://doi.org/10.1007/s40808-021-01093-9.

Baaghideh, M., Dadashi-Roudbari, A. & Beiranvand, F. 2020 Analysis of precipitation variation in the northern strip of Iran. *Modeling Earth Systems and Environment* **6** (1), 567–574. https://doi.org/10.1007/s40808-019-00703-x.

Bararkhanpour, S., Ghorbani, K., Salarijazi, M. & Rezaeighale, L. 2019 Analysis of seasonal changes in extreme temperatures using quantile regression (Case study: Hashem Abad Meteorological Station, Gorgan). *Journal of Meteorology and Atmospheric Science* **2** (2), 114–128.

Bararkhanpour, S., Ghorbani, K., Salari Jazi, M. & Rezaei Ghaleh, L. 2020 Study of seasonal and annual rainfall changes with quantile regression method (Case study: Gorgan Hashem-Abad Station). *Journal of Climate Research* **1398** (39), 89–104.

Bararkhanpour, S., Ghorbani, K., Salarijazi, M. & Rezaeighale, L. 2021 Analysis of trend of evaporation changes and determining the role of factors affecting it using quantile regression and Bayesian quantile regression (Case study: Hashem-Abad Station, Gorgan). *Journal of Climate Research* **1400** (46), 73–88.

Barbosa, S. M. 2008 Quantile trends in baltic Sea level. *Geophysical Research Letters* **35** (22), 1–6. https://doi.org/10.1029/2008GL035182.

Bazzi, H., Ebrahimi, H. & Aminnejad, B. 2021 A comprehensive statistical analysis of evaporation rates under climate change in southern Iran using WEAP (Case study: Chahnimeh Reservoirs Of Sistan Plain). *Ain Shams Engineering Journal* **12** (2), 1339–1352. https://doi.org/10.1016/j.asej.2020.08.030.

Benoit, D. F. & van den Poel, D. 2017 BayesQR: A Bayesian approach to quantile regression. *Journal of Statistical Software* **76** (1), 2–32. https://doi.org/10.18637/jss.v076.i07.

Bilal, B. M. F., Shahzad, K., Komal, B., Bashir, M. A., Bashir, M., Tan, D., Fatima, T. & Numan, U. 2021 Environmental quality, climate indicators, and COVID-19 pandemic: Insights from top 10 most affected states of the USA. *Environmental Science and Pollution Research* **28** (25), 1–10. https://doi.org/10.1007/s11356-021-12646-x.

Cannon, A. J. 2018 Non-crossing nonlinear regression quantiles by monotone composite quantile regression neural network, with application to rainfall extremes. *Stochastic Environmental Research and Risk Assessment* **32** (11), 3207–3225. https://doi.org/10.1007/s00477-018-1573-6.

Dinpashoh, Y., Jahanbakhsh-Asl, S., Rasouli, A. A., Foroughi, M. & Singh, V. P. 2019 Impact of climate change on potential evapotranspiration (Case study: West and NW Of Iran). *Theoretical and Applied Climatology* **136** (1–2). https://doi.org/10.1007/s00704-018-2462-0.

Donohue, R. J., McVicar, T. R. & Roderick, M. L. 2010 Assessing the ability of potential evaporation formulations to capture the dynamics in evaporative demand within a changing climate. *Journal of Hydrology* **386** (1–4). https://doi.org/10.1016/j.jhydrol.2010.03.020.

Dunn, R. J. H., Willett, K. M. & Parker, D. E. 2019 Changes in statistical distributions of sub-daily surface temperatures and wind speed. *Earth System Dynamics* **10** (4), 765–778. https://doi.org/10.5194/esd-10-765-2019.

Fathian, F., Ghadami, M., Haghighi, P., Amini, M., Naderi, S. & Ghaedi, Z. 2020 Assessment of changes in climate extremes of temperature and precipitation over Iran. *Theoretical and Applied Climatology* **141** (3–4), 1119–1133. https://doi.org/10.1007/s00704-020-03269-2.

Franco-Villoria, M., Scott, M. & Hoey, T. 2019 Spatiotemporal modeling of hydrological return levels: A quantile regression approach. *Environmetrics* **30** (2), e2522. https://doi.org/10.1002/env.2522.

Gao, M. & Franzke, C. L. E. 2017 Quantile regression-based spatiotemporal analysis of extreme temperature change in China. *Journal of Climate* **30** (24), 9897–9914. https://doi.org/10.1175/JCLI-D-17-0356.1.

Ghaedi, S. 2019 The variability and trends of monthly maximum wind speed over Iran. *Idojaras* **123** (4). https://doi.org/10.28974/idojaras.2019.4.7

Ghazi, B. & Jeihouni, E. 2022 Projection of temperature and precipitation under climate change in Tabriz, Iran. *Arabian Journal of Geosciences* **15** (7). https://doi.org/10.1007/s12517-022-09848-z.

Ghazi, B., Jeihouni, E., Kisi, O., Pham, Q. B. & Đurin, B. 2022 Estimation of Tasuj aquifer response to main meteorological parameter variations under Shared Socioeconomic Pathways scenarios. *Theoretical and Applied Climatology* **149** (1–2). https://doi.org/10.1007/s00704-022-04025-4.

Gilliland, J. M. & Keim, B. D. 2018 Surface wind speed: Trend and climatology of Brazil from 1980–2014. *International Journal of Climatology* **38** (2), 1060–1073. https://doi.org/10.1002/joc.5237.

Hosseinalizadeh, M., Alinejad, M., Mohammadian Behbahani, A., Khormali, F., Kariminejad, N. & Pourghasemi, H. R. 2020 A review on the gully erosion and land degradation in iran. In: Advances in Science, Technology and Innovation. https://doi.org/10.1007/978-3-030-23243-6_26.

Hounguè, R., Lawin, A. E., Moumouni, S. & Afouda, A. A. 2019 Change in climate extremes and pan evaporation influencing factors over Ouémé Delta in Bénin. *Climate* **7** (1), 1–22. https://doi.org/10.3390/cli7010002.

Javanshiri, Z., Pakdaman, M. & Falamarzi, Y. 2021 Homogenization and trend detection of temperature in Iran for the period 1960–2018. *Meteorology and Atmospheric Physics* **133** (4), 1233–1250. https://doi.org/10.1007/s00703-021-00805-1.

Kalisa, W., Igbawua, T., Ujoh, F., Aondoakaa, I. S., Namugize, J. N. & Zhang, J. 2021 Spatio-temporal variability of dry and wet conditions over East Africa from 1982 to 2015 using quantile regression model. *Natural Hazards* **106** (3), 1–30. https://doi.org/10.1007/s11069-021-04530-1.

Karimi, M., Vicente-Serrano, S. M., Reig, F., Shahedi, K., Raziei, T. & Miryaghoubzadeh, M. 2020 Recent trends in atmospheric evaporative demand in Southwest Iran: Implications for change in drought severity. *Theoretical and Applied Climatology* **142** (3–4), 945–958. https://doi.org/10.1007/s00704-020-03349-3.

Kendall, M. G. 1975 *Rank Correlation Methods*, 4th edn. Charles Griffin, San Francisco, CA.

Koenker, R. 2005 *Quantile Regression*. Cambridge University Press. https://doi.org/10.1017/CBO9780511754098.

Koenker, R. 2010 *Quantile Regression in R: A Vignette*. Quantile Regression. https://doi.org/10.1017/cbo9780511754098.011.

Koenker, R. 2022 *Package 'Quantreg' Title Quantile Regression*, pp. 1–112. https://doi.org/10.1017/CBO9780511754098.

Koenker, R. & Bassett, G. 1978 Regression quantiles. *Econometrica* **46** (1), 33–50. https://doi.org/10.2307/1913643.

Koenker, R. W. & D'Orey, V. 1987 Algorithm AS 229: Computing regression quantiles. *Applied Statistics* **36** (3), 383–393. https://doi.org/10.2307/2347802.

Koenker, R. & Hallock, K. F. 2001 Quantile regression. *Journal of Economic Perspectives* **15** (4), 143–156. https://doi.org/10.1257/JEP.15.4.143.

Kousali, M., Salarijazi, M. & Ghorbani, K. 2022 Estimation of non-Stationary behavior in annual and seasonal surface freshwater volume discharged into the Gorgan Bay, Iran. *Natural Resources Research* **31** (2), 835–847. https://doi.org/10.1007/s11053-022-10010-5.

Lee, K., Baek, H. J. & Cho, C. 2013 Analysis of changes in extreme temperatures using quantile regression. *Asia-Pacific Journal of Atmospheric Sciences* **49** (3), 313–323. https://doi.org/10.1007/s13143-013-0030-1.

Machekposhti, K. H., Sedghi, H., Telvari, A. & Babazadeh, H. 2018 Modeling climate variables of rivers basin using time series analysis (Case study: Karkheh River Basin at Iran). *Civil Engineering Journal* **4** (1), 78–92. https://doi.org/10.28991/cej-030970.

Mahmoudi, P., Mohammadi, M. & Daneshmand, H. 2019 Investigating the trend of average changes of annual temperatures in Iran. *International Journal of Environmental Science and Technology* **16** (2), 1079–1092. https://doi.org/10.1007/s13762-018-1664-4.

Mann, H. B. 1945 Mann nonparametric test against trend. *Econometrica* **13** (3), 245–259.

Minaei, M. & Irannezhad, M. 2018 Spatio-temporal trend analysis of precipitation, temperature, and river discharge in the northeast of Iran in recent decades. *Theoretical and Applied Climatology* **131** (1–2), 167–179. https://doi.org/10.1007/s00704-016-1963-y.

Mirdashtvan, M., Najafinejad, A., Malekian, A. & Sa'doddin, A. 2020 Regional analysis of trend and non-stationarity of hydro-climatic time series in the Southern Alborz Region, Iran. *International Journal of Climatology* **40** (4), 1979–1991. https://doi.org/10.1002/joc.6313.

Moghim, S. 2018 Impact of climate variation on hydrometeorology in Iran. *Global and Planetary Change* **170**, 93–105. https://doi.org/10.1016/j.gloplacha.2018.08.013.

Mohsenipour, M., Shahid, S., Ziarh, G. F. & Yaseen, Z. M. 2020 Changes in monsoon rainfall distribution of Bangladesh using quantile regression model. *Theoretical and Applied Climatology* **142** (3–4), 1329–1342. https://doi.org/10.1007/s00704-020-03387-x.

Moosavi, A. A. 2020 Spatial zoning of pan evaporation and affecting variables using geostatisitc methods (Case study: Fars Province). *Journal of Agricultural Meteorology* **7** (2), 44–54. https://doi.org/10.22125/AGMJ.2019.113709.0.

Mozny, M., Trnka, M., Vlach, V., Vizina, A., Potopova, V., Zahradnicek, P., Stepanek, P., Hajkova, L., Staponites, L. & Zalud, Z. 2020 Past (1971–2018) and future (2021–2100) pan evaporation rates in the Czech Republic. *Journal of Hydrology* **590**, 125390. https://doi.org/10.1016/j.jhydrol.2020.125390.

Nasrollahi, M., Zolfaghari, A. A. & Yazdani, M. R. 2021a Spatial and temporal properties of reference evapotranspiration and Its related climatic parameters in the main agricultural regions of Iran. *Pure and Applied Geophysics* **178** (10), 4159–4179. https://doi.org/10.1007/s00024-021-02806-y.

Nasrollahi, M., Zolfaghari, A. A. & Yazdani, M. R. 2021b Investigation of Pan evaporation paradox and climatic parameters affecting it in half-west and center of Iran. *Journal of Water and Soil Resources Conservation* **11** (1), 61–76. https://doi.org/10.30495/WSRCJ.2021.18545.

Nian, D., Linz, M., Mooring, T. A. & Fu, Z. 2022 The changing extreme values of summer relative humidity in the Tarim Basin in northwestern China. *Climate Dynamics* **58** (11–12), 3527–3540. https://doi.org/10.1007/s00382-021-06110-2.

Niu, Z., Wang, L., Chen, X., Yang, L. & Feng, L. 2021 Spatiotemporal distributions of pan evaporation and the influencing factors in China from 1961 to 2017. *Environmental Science and Pollution Research* **28** (48), 68379–68397. https://doi.org/10.1007/s11356-021-15386-0.

Nouri, M., Homaee, M. & Bannayan, M. 2018 Spatiotemporal reference evapotranspiration changes in humid and semi-arid regions of Iran: Past trends and future projections. *Theoretical and Applied Climatology* **133** (1–2), 361–375. https://doi.org/10.1007/s00704-017-2176-8.

Pettitt, A. N. 1979 A non-parametric approach to the change-point problem. *Applied Statistics* **28** (2), 126–135. https://doi.org/10.2307/2346729.

Pumo, D. & Noto, L. V. 2021 Exploring the linkage between dew point temperature and precipitation extremes: A multi-time-scale analysis on a semi-arid Mediterranean region. *Atmospheric Research* **254**, 105508. https://doi.org/10.1016/j.atmosres.2021.105508.

Raziei, T. 2022 Climate of Iran according to Köppen-Geiger, Feddema, and UNEP climate classifications. *Theoretical and Applied Climatology* **148** (3–4). https://doi.org/10.1007/s00704-022-03992-y.

Reich, B. J. 2012 Spatiotemporal quantile regression for detecting distributional changes in environmental processes. *Journal of the Royal Statistical Society. Series C: Applied Statistics* **61** (4), 535–553. https://doi.org/10.1111/j.1467-9876.2011.01025.x.

Ruiz-Alvarez, O., Singh, V. P., Enciso-Medina, J., Munster, C., Kaiser, R., Ontiveros-Capurata, R. E., Diaz-Garcia, L. A. & Costa dos Santos, C. A. 2019 Spatio-temporal trends in monthly pan evaporation in Aguascalientes, Mexico. *Theoretical and Applied Climatology* **136** (1–2), 775–789. https://doi.org/10.1007/s00704-018-2491-8.

Salman, S. A., Shahid, S., Ismail, T., Ahmed, K. & Wang, X. J. 2018 Selection of climate models for projection of spatiotemporal changes in temperature of Iraq with uncertainties. *Atmospheric Research* **213**, 509–522. https://doi.org/10.1016/j.atmosres.2018.07.008.

Sen, P. K. 1968 Estimates of the regression coefficient based on Kendall's Tau. *Journal of the American Statistical Association* **63** (324), 1379–1389. https://doi.org/10.1080/01621459.1968.10480934.

Shadmani, M., Marofi, S. & Roknian, M. 2012 Trend analysis in reference evapotranspiration using Mann-Kendall and spearman's Rho tests in arid regions of Iran. *Water Resources Management* **26** (1). https://doi.org/10.1007/s11269-011-9913-z

Shah, L., Arnillas, C. A. & Arhonditsis, G. B. 2022 Characterizing temporal trends of meteorological extremes in Southern and Central Ontario, Canada. *Weather and Climate Extremes* **35**, 100411. https://doi.org/10.1016/j.wace.2022.100411.

Shamsipour, A. & Rodgar Safari, V. 2020 Investigating the consequences of climate change with a focus on spatial analysis of drought severity in golestan province using statistical and remote sensing indices. *Climate Change Research* **1** (3), 65–76. https://doi.org/10.30488/CCR.2020.246770.1022.

Silakhori, E., Dahmardeh Ghaleno, M. R., Meshram, S. G. & Alvandi, E. 2022 To assess the impacts of climate change on runoff in Golestan Province, Iran. *Natural Hazards* **112** (1), 281–300. https://doi.org/10.1007/S11069-021-05181-Y.

Solaimani, K. & Bararkhanpour, S. 2022 Spatiotemporal changes of climatic parameters extreme quantiles and their role on evaporation in N. Iran (Golestan province). *Arabian Journal of Geosciences* **15** (1), 1–16. https://doi.org/10.1007/s12517-021-09300-8.

Soroush, F., Fathian, F., Khabisi, F. S. H. & Kahya, E. 2020 Trends in pan evaporation and climate variables in Iran. *Theoretical and Applied Climatology* **142** (1–2), 407–432. https://doi.org/10.1007/s00704-020-03262-9.

Stephens, C. M., McVicar, T. R., Johnson, F. M. & Marshall, L. A. 2018 Revisiting pan evaporation trends in Australia a decade on. *Geophysical Research Letters* **45** (20), 11,164–11,172. https://doi.org/10.1029/2018GL079332.

Treppiedi, D., Cipolla, G., Francipane, A. & Noto, L. V. 2021 Detecting precipitation trend using a multiscale approach based on quantile regression over a Mediterranean area. *International Journal of Climatology* **41** (13), 5938–5955. https://doi.org/10.1002/joc.7161.

Wasko, C. & Sharma, A. 2014 Quantile regression for investigating scaling of extreme precipitation with temperature. *Water Resources Research* **50** (4). https://doi.org/10.1002/2013WR015194

Wu, X., Meng, F., Liu, P., Zhou, J., Liu, D., Xie, K., Zhu, Q., Hu, J., Sun, H. & Xing, F. 2021 Contribution of the northeast cold vortex index and multiscale synergistic indices to extreme precipitation over northeast China. *Earth and Space Science* **8** (1), 1–17. https://doi.org/10.1029/2020EA001435.

Yao, L., Lu, J., Zhang, W., Qin, J., Zhou, C., Tran, N. N. & Pinagé, E. R. 2022 Spatiotemporal analysis of extreme temperature change on the Tibetan plateau based on quantile regression. *Earth and Space Science* **9** (11). https://doi.org/10.1029/2022EA002571

Zhang, S., Gan, T. Y. & Bush, A. B. G. 2020 Variability of Arctic sea ice based on quantile regression and the teleconnection with large-scale climate patterns. *Journal of Climate* **33** (10), 4009–4025. https://doi.org/10.1175/JCLI-D-19-0375.1.

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