Caspian Journal of Environmental Sciences

Online ISSN: 1735-3866
Print ISSN: 1735-3033

Are precipitation characteristics and patterns impacting oak trees decline in the Zagros region of western Iran?

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ABSTRACT
The objective was to investigate if changes in annual, monthly, and seasonal precipitation are associated with emergence of declining oak trees in Iran. Daily precipitation data were obtained from 20 synoptic stations distributed over the Zagros area from 1988-2019. Non-parametric Mann-Kendall (MK) test and Sen's Slope estimator (Q_{med} value) were applied to identify significant trends in the precipitation data. ''De Martonne'' climate classification (i.e., De Martonne aridity index (I_{DM}) was used for climate classification. Although most stations showed decreasing trends in annual precipitation during the studied period (1988-2019), these trends were statistically significant at only two stations. The mean number of events per year pre- and post- oak decline was not significantly different (68 events before against 71 events after decline). Most of the annual precipitation in the Zagros region falls in winter and spring (80% in total). However, this ratio decreased after the year 2000 by 6% (not significant) compared with before. The difference between the average annual precipitation, before (1988-2000) and after (2000-2019) the emergence of the oak decline phenomenon, were not statistically significant in any of the climate types (semi-arid: 406 mm vs. 378 mm), Mediterranean (530 mm vs. 489 mm), and humid (924 mm vs. 912 mm) as well as in whole Zagros region (537 mm vs. 508 mm). Although our data suggested insignificant trends in precipitation for most stations, future research should investigate if rising temperature in the Zagros area has resulted in higher evaporation and drier soil thereby accelerating the oak tree decline.

Keywords: Climate change, Mann–Kendall test, *Quercus brantii*.
Article type: Research Article.

INTRODUCTION
The Zagros vegetation zone is characterized as a semi-arid temperate climate that extends from Piranshahr in northwest Iran to the vicinity of Firooz-Abad with a length of 1300 km and 200 km in width (Fattahi 2001; Gheibi *et al.* 2021). The mean annual precipitation ranges from 300 mm to 1000 mm (Jazirehi & Ebrahimi 2003; SaghebTalebi *et al.* 2014) and most of the precipitation occurs in the non-growing season (autumn and winter).

Caspian Journal of Environmental Sciences, Vol. 21 No. 4 pp. 753-765 Received: March 22, 2023 Revised: May 11, 2023 Accepted: July 06, 2023
DOI: 10.22124/CJES.2023.7122

Publisher: University of Guilan,

Approximately, 5-6 million ha of the zone is covered by forest that is dominated by the Persian oak (*Quercus brantii* var. *persica*) trees. Oak-decline has been recognized as a critical issue in the region in the past few decades (Azizi *et al.* 2015; Pourhashemi *et al.* 2015). Oak trees in the west of Iran have been in decline since 2000 (Beiranvand *et al.* 2015). The decline has been known as "Oak silent death" and its symptoms occur quickly and abruptly then the oak trees rapidly dry up over a few months (Pourhashemi *et al.* 2017; Zandebasiri *et al.* 2017). Oak-decline has resulted in crown thinning, foliar necrosis, as well as the gradual death of the main leaves and the emergence of oak trees dieback since 2000 (Mirzaei *et al.* 2018). Several biotic and abiotic factors have been considered to be important in the oak-decline phenomenon. The main reasons proposed for oak-decline are climate conditions, drought, storms, heat, insect damage, disease outbreaks, as well as human disturbance (Attarod *et al.* 2017). Increases in extreme climatic events, such as summer drought and winter frost, may play a vital role in the oak-decline phenomenon (Doležal *et al.* 2010; Attarod *et al.* 2017). Researchers have reported that the decline of oak trees is linked to an accumulated deficit of precipitation, together with an increase in temperature as one of the most important climatic factors (Sánchez & García 2007). A concern associated to the effects of climate change on natural ecosystems is the response of the earth's hydrological cycle to global warming (Giorgi *et al.* 2019). Increase global temperatures can result in a more active hydrological cycle and increase the water-holding capacity of the atmosphere, leading to changes in precipitation (Dore 2005). Precipitation patterns have been altered by climate change, especially in arid and semi-arid regions (Kirilenko & Sedjo 2007). Climate change affects the hydrological cycle by interfering with the seasonal distribution of precipitation, increased precipitation intensity, temperature fluctuations, increased evapotranspiration, and reduced soil moisture (Pathak *et al.* 2014). Some researchers believe that the growth and productivity of oak trees in the Mediterranean environments is coupled with precipitation in late spring-early summer as well as the previous autumn (Di Filippo *et al.* 2010). The main goal of this study was to investigate the annual, monthly, and seasonal rainfall changes pre- and post-Persian oak decline in the Zagros vegetation zone of western Iran.

MATERIALS AND METHODS

Sampling and analysis of samples

This research was conducted in the Zagros vegetation area of Iran. This zone is, located along the Zagros Mountains range that extends from the northwest to southwest of Iran. The main species are Persian oak, wild pistachio (*Pistacia atlantica*), *Crataegus* spp., and *Pyrus* spp. (Jazirehi & Rostaghi 2003; Fig.1).

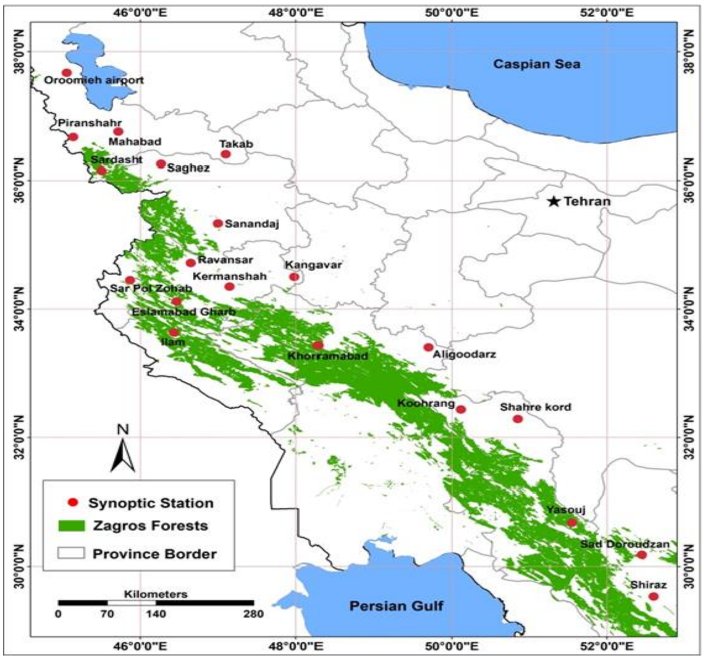

Fig. 1. Locations of the Zagros forest in the west of Iran and used synoptic meteorological stations.

Daily precipitation data at twenty synoptic meteorological stations were used to study precipitation changes in the Zagros vegetation area over 32-year period (1988-2019; Table 1). We classified the weather stations into semi-dry (mean annual precipitation: 390 mm), Mediterranean (506 mm), and humid (916 mm) climate types in order to have better understating the precipitation changes in the Zagros region. Sixty percent of the study regions were classified as the semi-dry climate type and the I_{DM} value for this climate varied from 10 to 20 (Table 1). Both the Mediterranean and humid/very humid climate types were present at the four weather stations (Table 1).

Table 1. Geographic characteristics of the synoptic meteorological stations and long-term (1988-2019) values of annual precipitation and related statistics including Z values of the Mann–Kendall test (MK value) and the Sen's slope estimator (Q_{med} value) for annual precipitation recoded by the weather stations in the Zagros region of western Iran during 1988–2019. The de Martonne aridity index (I_{DM}) was adapted after Baltas (2007).

Station	Elevation (m asl)	Longitude (E)	Latitude (N)	I_{DM} (Climate)	Mean (mm)	Max/period (mm)	Min/period (mm)	SD (mm)	CV (%)	MK value	Q_{med} value (mm/year)
Aligoodarz	2022	49º 42'	33º 24'	17.3 (Semi-dry)	395	584	174	105	27	0.2	0.5
Eslamabad Gharb	1348.8	46º 28'	34º 07'	20.1 (Mediterranean)	480	824	293	129	27	0.02	-0.1
Ilam	1337	46º 26'	33º 38'	21.6 (Mediterranean)	583	997	337	175	30	-0.51	-2.2
Kangavar	1468	47º 59'	34º 30'	17.4 (Semi-dry)	404	662	222	107	26	0.8	1.1
Kermanshah	1318.6	47º 09'	34º 21'	16.7 (Semi-dry)	424	703	216	107	25	-0.68	-1.7
Khorramabad	1147.8	48º 17'	33º 26'	18.1 (Semi-dry)	490	835	271	146	30	0.08	0.1
Koohrang	2285	50º 07'	32º 26'	68.0 (Very -Humid)	1346	2040	565	374	28	-1.38	-11.8
Mahabad	1351.8	45º 43'	36º 45'	17.3 (Semi-dry)	404	678	225	101	25	-0.49	-1.3
Oroomieh airport	1328	45º 03'	37º 40'	14.1 (Semi-dry)	308	579	167	92	31	1.2	0.4
Piranshahr	1455	45º 08'	36º 40'	29.4 (Humid)	673	1121	398	186	28	1.06	4.2
Ravansar	1379.9	46º 39'	34º 43'	20.8 (Mediterranean)	524	794	334	128	24	-0.66	-1.2
Sad Doroudzan	1652	52º 27'	30º 11'	16.3 (Semi-dry)	458	848	160	146	32	-2.5**	-6.7**
Saghez	1522.8	46º 16'	36º 15'	20.8 (Mediterranean)	437	791	273	124	28	1.88	2.1
Sanandaj	1373.4	47º 00'	35º 20'	15.9 (Semi-dry)	385	645	236	95	25	-1.73	-3.7
Sardasht	1670	45º 30'	36º 09'	36.0 (Very -Humid)	845	1255	505	210	25	0.59	2.7
Sar Pol Zohab	545	45º 52'	34º 27'	14.3 (Semi-dry)	435	950	250	133	31	-1.6	-3.5
Shahre Kord	2048.9	50º 51'	32º 17'	14.8 (Semi-dry)	319	527	141	93	29	-0.6	-1.1
Shiraz	1484	52º 36'	29º 32'	11.2 (Semi-dry)	322	622	97	112	35	-1.97*	-4.3*
Takab	1817.2	47º 06'	36º 24'	16.3 (Semi-dry)	321	527	176	86	27	-0.17	-1.7
Yasouj	1816.3	51º 33'	30º 41'	32 (Humid)	803	1294	294	221	28	-0.66	-6.4
Zagros region				22.0 (Mediterranean)	519	2040	97	287	54	-0.08	-1.6

Statistical processing and data analysis

Mann-Kendall (MK) Test

To investigate the precipitation trend, Mann-Kendall (MK) test was used to determine the precipitation trend at 99% and 95% confidence levels. The MK test is a statistical method which mostly used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of monotonic increasing or decreasing trend of hydro-climatic time series data (Hussain 2015; Rostami *et al.* 2022). The non-parametric MK test is used for detecting trends of variables in meteorology and hydrology fields (Wang *et al*. 2019).

The statistic S is calculated as shown in Eq. 1:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad \textbf{(1)}$$

If n is bigger than 8, statistic S approximates to normal distribution. The mean of S is 0 and the variance of S can be acquired as follows Eqs. 2 and 3:

$$Var\ (S) = \frac{\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t(t-1)(2t+5)\right]}{18} \quad \textbf{(2)}$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \quad \textbf{(3)}$$

Then the test statistic Z is denoted by Eq. 4.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(s)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{VAR(s)}} & if \quad S < 0 \end{cases} \quad \textbf{(4)}$$

A positive value of Z shows upwards (increasing) trend while the negative value indicates downward (decreasing) one. When the MK statistic (Z_{MK}) is greater than 1.96 and 2.58 (based on normal probability table), there is a significant increasing trend (α = 0.05 and α = 0.01), whereas negative Z_{MK} values lower than -1.96 and -2.58 show significant decreasing trends (α = 0.05 and α = 0.01; Hussain 2015).

Sen's Slope Estimator

Sen's non-parametric estimator method has been used for predicting the magnitude (true slope) of hydro metrological time series (Sen 1968). This method uses a linear model for the trend analysis (Hussain *et al.* 2015). The slope of "n" pairs of data can be first estimated by using Eq. (5):

$$\beta_i = Median \left[\frac{X_j - X_k}{j-k}\right] \forall\ (k < j) \quad \textbf{(5)}$$

A negative βi value represents a decreasing trend while a positive βi value represents an increasing trend over time.

$$Qmed = \left[\frac{n+2}{2}\right] \quad \textbf{(6)}$$

If "n" is an odd number, then the estimated slope using the Sen's method can be computed by Eq. (7)

$$Q_{med} = [(n+1)/2] \quad \textbf{(7)}$$

Q_{med} is tested by a two tailed test at 100 (1−α) % confidence level, and the true slope of monotonic trend can be estimated using a nonparametric test (Ali & Abubaker 2019). A positive value of Q_{med} indicates an increasing (upward) trend, while negative value shows downward or decreasing trend of time series data (Hussain *et al.* 2015).

RESULTS AND DISCUSSION

Annual Trends of Precipitation

From 1988 to 2019, the highest and lowest mean annual precipitation in the Zagros area were recorded in Koohrang (1346 mm) and Oroomieh (308 mm), respectively (Table 1). During this period, the absolute maximum and minimum annual precipitation were recorded in Koohrang (2040 mm), and Shiraz (97 mm), respectively. The largest difference between the minimum and maximum annual precipitation was in Koohrang (1475 mm), and the lowest difference was in Takab (351 mm; Table 1). The percent of coefficient of variation (CV %) of annual precipitation ranged from 24% to 35% (Table 1).

When data from all the stations were averaged, the annual precipitation was found to be 519 mm (SD: 287 mm; Table 1). From 1988-2019, annual precipitation declined at 13 stations, and increased at 6 stations, however, only the Sad Doroudzan and Shiraz stations had significant trends. Both stations experienced significant declines in annual precipitation from 1988 to 2019 (Table 1). Q_{med} value was furthest from zero at Koohrang station (-11.8 mm per year), while closest to zero at Eslamabad Gharb (-0.1 mm per year) and Khorramabad (0.1 mm per year; Table 1).

Table 2. The mean precipitation event size (mm) (±standard deviation) and related statistics over the 32-year period (1988-2019) and before and after the phenomenon of oak trees decline (the year 2000). The parentheses indicate the largest event (mm) during the period.

Station	**Before 2000**	**After 2000**	**32-year period**
Aligoodarz	5.8 ± 1.5 (64)	5.7 ± 0.8 (62)	5.7 ± 1.1 (64)
Eslamabad Gharb	6.7 ± 1.1 (97)	6.9 ± 1.4 (86)	6.8 ± 1.3 (97)
Ilam	8.7 ± 1.4 (103)	8.8 ± 2.1 (282)	8.7 ± 1.8 (282)
Kangavar	5.4 ± 1.0 (53)	5.6 ± 1.2 (110)	5.5 ± 1.1 (110)
Kermanshah	5.8 ± 1.2 (108)	6.1 ± 0.9 (73)	5.9 ±1.0 (108)
Khorramabad	7.3 ± 1.1 (70)	7.5 ± 1.9 (107)	7.4 ± 1.6 (107)
Koohrang	16.4 ± 3.8 (145)	16.2 ± 4.2 (188)	16.3 ± 4.0 (188)
Mahabad	5.3 ± 1.0 (56)	5.2 ± 1.2 (68)	5.3 ± 1.1 (68)
Oroomieh airport	4.3 ± 1.0 (61)	6.4 ± 0.9 (64)	5.3 ± 1.0 (64)
Piranshahr	7.8 ± 1.6 (89)	8.2 ± 1.7 (80)	8.0 ± 1.7 (89)
Ravansar	6.9± 0.9 (73)	7.1 ± 1.4 (95)	7.0 ± 1.2 (95)
Sad Doroudzan	10.5 ± 1.5 (79)	10.1± 3.2 (93)	10.3 ± 2.6 (93)
Saghez	6.0 ± 1.5 (79)	5.1 ± 0.7 (61)	5.5 ± 1.2 (79)
Sanandaj	5.9 ± 0.9 (73)	5.3 ± 0.7 (66)	5.6 ± 0.9 (73)
Sardasht	9.3 ± 1.9 (132)	9.8 ± 1.6 (185)	9.6 ± 1.7 (185)
Sar Pol Zohab	7.1 ± 1.4 (102)	6.8 ± 1.3 (138)	6.9 ± 1.4 (138)
Shahre Kord	5.5 ± 1.0 (76)	6.3 ± 1.8 (89)	6.0 ± 1.5 (89)
Shiraz	8.0 ± 1.8 (75)	7.1 ± 2.1 (69)	7.5 ± 2.0 (75)
Takab	3.6± 0.8 (53)	3.5 ± 0.5 (42)	3.5 ± 0.6 (53)
Yasouj	12.6± 1.7 (120)	15.3 ± 3.3 (151)	13.0 ± 2.8 (151)
Zagros region	7.5 ± 3.3 (145)	7.4 ± 3.5 (282)	7.5 ± 3.4 (282)

Comparing the annual precipitation values before and after emerging time of the oak decline phenomenon, no significant differences were observed in the weather stations (537 mm before against 508 after emerging time; Fig. 2). The highest amount of precipitation in the semi-arid, Mediterranean, and humid climates were recorded in the Khorramabad (490 mm), Ilam (583 mm), and Koohrang (1346 mm) stations, respectively. The MK test revealed the absence of significant trends for annual precipitation at the semi-arid (MK value: 0.15), Mediterranean (-0.49), and humid (0.5) climates. Similarly, we detected no significant difference between annual precipitation before and after emerging oak decline in dissimilar climates (Fig. 2).

Globally, precipitation over land has increased by 2% during the last century (New *et al.* 2001), however, precipitation has significantly declined over Iran during the last fifty years (Tabari & Hosseinzadeh Talaee 2011). In this study, we analyzed the annual precipitation trend for the Zagros region of western Iran for the period 1988–2019. Our findings showed that there was a trend towards decreasing annual precipitation at the majority of stations (65%), however, the decline was significant at only 10% of all the stations across Zagros region. Tabari *et al.* (2010) reported that about 60% of the stations over Iran had a significant decreasing trend during (1966-2005). In addition, Zarenistanak *et al.* (2014) reported significant increases in precipitation at 16% of stations in Southwest Iran. Similar to our study, Raziei *et al.* (2005) reported that most of the synoptic stations located in arid and semi-arid climates of Iran were characterized by an insignificant change in annual precipitation.

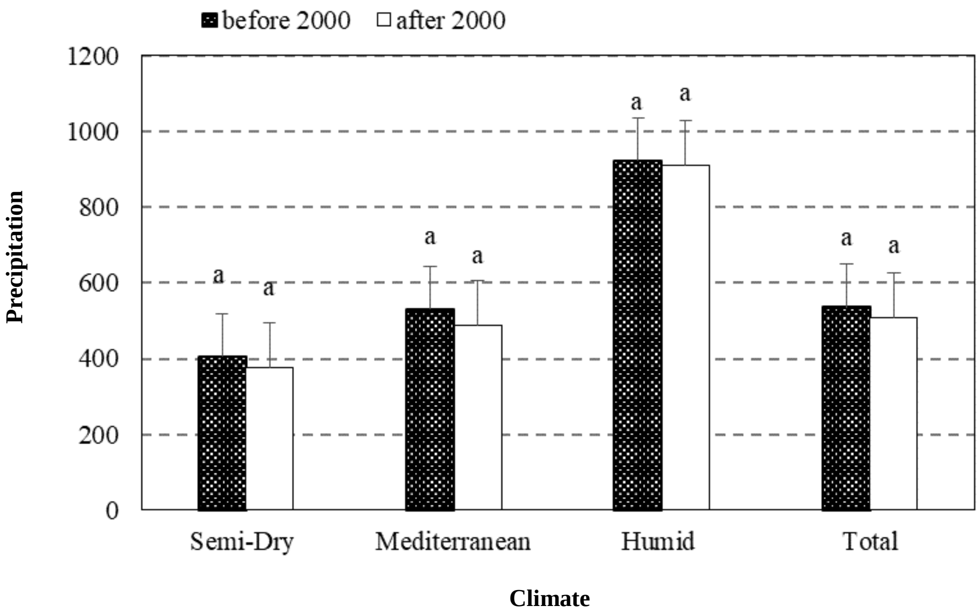

Fig. 2. Average annual precipitation before and after the emerging time of oak decline phenomenon (the year 2000) in the semi-arid, Mediterranean, and humid climate types of the Zagros region. Bar lines show the standard deviation of mean yearly precipitation. Dissimilar letters indicate significant difference at 95%.

We found out that annual precipitation tended to decline after the emerging the oak decline phenomenon in the Zagros region of Western Iran (29 mm), but this trend was not significant. This decrease has been observed in semi-arid (28 mm), Mediterranean (41 mm), and humid (12 mm) climate types. Previous studies in the Zagros region have also shown that after the emergence of the decline phenomenon, the annual precipitation decreased by about 50 mm (between 2000 and 2010; Attarod *et al.* 2016). To clearly see a change in precipitation, more time may be needed to result in a significant result as inter annual variability may mask a significant trend.

Precipitation event size

During the whole period (1988-2019), mean precipitation per event ranged from 16.3 mm at Koohrang station to 3.5 mm at Takab (Table 2). Moreover, the highest variation of precipitation events (SD) was in Koohrang (4 mm). During this period, the absolute maximum precipitation event occurred at Ilam (282 mm; Table 2). In few stations, mean precipitation event size appeared to change following the emergence of oak decline, however, these changes were not significant (e.g., Oroomieh airport 4.3 mm vs. 6.4 mm; Saghez 6.0 mm vs. 5.1 mm; Shiraz 8.0 mm vs. 7.1 mm; Yasouj 12.6 mm vs. 15.3; Table 2). In the Zagros region, the mean precipitation event size did not significantly change before (7.5 mm) and after (7.4 mm) the start of the oak-decline phenomenon (Table 2). On average, absolute maximum precipitation events were larger by approximately 40 mm after emerging oak decline for all stations (Table 2). However, the MK test showed no significant trend in the mean precipitation event size for all stations as well as for the whole Zagros region in total (MK = 0.15).

Event scale mean and variation in precipitation were not significantly different before and after emerging oak decline in all climate types (see Table 3). Moreover, the absolute maximum precipitation events were larger in all climate types after emerging oak decline, i.e., the semi-dry (108 mm vs. 138 mm), the Mediterranean (103 mm vs. 282 mm) and humid (145 mm vs. 188 mm; Table 3). In general, the trends of mean precipitation event size were insignificant for all stations and for the whole Zagros region. There was no significant difference in the mean event size before and after the oak decline phenomenon (Table 2). The largest event size over the 32-year period occurred after the decline (282 mm), however, the mean number of events per year after the decline did not change (68 events before against 71 events after decline). The largest event throughout the Zagros region was observed in the Mediterranean climate at Ilam (282 mm). The Mediterranean climate is exposed to mid-latitude weather in winter and subtropical dryness in summer (Polade *et al.* 2017). Therefore, it is expected to be more affected by climate change than other climates (Giorgi 2006). Generally, a drop in precipitation events combined with an elevation in the amount of precipitation applies to all regions with a Mediterranean climate, and water resources become more volatile (Polade *et al*. 2017).

Table 3. The mean precipitation event size (mm) (±standard deviation) and related statistics over the 32-year period (1988-2019) and before and after the phenomenon of oak trees decline (the year 2000) in the diverse climate types in the Zagros region of western Iran. The parentheses indicate the largest event (mm) during the period.

Climate	Before 2000	After 2000	32-year period
Semi-dry	6.3 ± 1.2 (108)	6.3 ± 1.4 (138)	6.3 ± 1.3 (138)
Mediterranean	7.1 ± 1.2 (103)	7.0 ± 1.4 (282)	7.0 ± 1.4 (282)
Humid	11.5 ± 2.2 (145)	11.9 ± 2.7 (188)	11.7± 2.5 (188)

Seasonal precipitation changes

Across the Zagros region, the largest seasonal precipitation events were recorded in winter (657 mm), spring (471 mm), and autumn (215 mm) in Koohrang respectively, whereas the greatest precipitation event in the summer was recorded at Oroomieh (19 mm; Table 4). In contrast, the lowest precipitation amount during the winter, spring, and summer were recorded at Oroomieh airport (84 mm), Shiraz (80 mm) and Sar Pol Zohab (0.7 mm), respectively. Shiraz recorded the smallest amount of autumn precipitation (39 mm; Table 4). For the whole Zagros region, 44% (237 mm) and 36% (183 mm) of yearly precipitation occurred in the winter and spring, respectively (Table 4). The largest and smallest average seasonal precipitation rates (%) occurred in winter (mean 44%) and summer (mean 1%) in all climate types respectively (Table 5). The summer precipitation rate (%) was equal in all climate types (1%; Table 5). Comparison of average seasonal precipitation indicated that the highest winter (48%, 446 mm), spring (37%, 141 mm), and autumn (20%, 103 mm) precipitation rates (%) were recorded in the humid, semi-arid, and Mediterranean climates, respectively (Table 5). During the whole period (1988-2019), 30% of the stations had significant decline in winter precipitation including Kermanshah (MK = -1.98), Sad Dorudzan (MK = -2.89), Sar Pol Zohab (MK = -2.81), Shahre Kord (MK = -1.98), Shiraz (MK = -2.89), and Yasouj (MK= -2). In the summer season, Takab was the only station with a significant declining trend (MK = -2.2). There were no significant trends in either spring or autumn at any station. Throughout the Zagros region the mean winter, spring, and summer precipitation rates changed slightly after emerging oak decline comparing before. However, these changes were not significant (winter 47% vs. 43%; spring 37% vs. 35%; and summer 15% vs. 21%). Furthermore, the average seasonal precipitation distribution after the emerging oak decline compared with before, exhibited similar conditions in all climate types (Table 5). The largest decrease of winter and spring precipitations after the oak decline phenomenon occurred in semi-arid (5%, 29 mm), and Mediterranean (2%, 20 mm) climates, respectively (Table 5). However, decrease of winter and spring precipitations after the oak decline phenomenon was not significant. The autumn precipitation increased after the oak decline phenomenon in the diverse climate types, while the most increased elevated values were recorded in the semi-arid (6%, 14 mm) and Mediterranean (6%, 11 mm) climates. Our analysis showed that summer precipitation had no significant changes after the oak decline phenomenon in all climate types (Table 5). The results indicated that the mean winter precipitation may have decreased after the initiation of oak-decline (2000) for portions of the Zargos region (Table 5). At seasonal scale, nearly half of the annual precipitation in the Zagros region falls in winter (about 44%, 237 mm). About 30% of the stations exhibited significant decreasing trends for the winter precipitation. Khalili *et al.* (2016) also demonstrated that precipitation in the winter has been decreasing within the second 25-year period (1961-2010) in Iran. Tabari & Hosseinzadeh Talaee (2011) also reported that most of the trends in winter precipitation were significantly decreasing over Iran for the period 1966–2005. Precipitation is the main climate driver for tree growth and changes in precipitation patterns, controls vegetation growth. The reduction of precipitation in the winter and spring leads to the impaired vegetation growth (Xu *et al.* 2017), since winter precipitation is critical for breaking dormancy (Daşci *et al.* 2010). Therefore, shifting precipitation from winter and spring to autumn reduces the access of oak trees to water resources, hence elevating the water stress. So, changing the pattern of seasonal precipitation may be one of the factors that intensify the phenomenon of decline in some areas of the Zargos region.

Table 4. The mean seasonal precipitation (mm) (±standard deviation) over the 32-year period (1988-2019) for each synoptic station. Numbers in parentheses indicate the minimum and maximum annual precipitation during the period in the season.

Station	Winter	Spring	Summer	Autumn	Year
Aligoodarz	151 ± 58 (64-314)	164 ± 71 (60-328)	5 ± 7 (0-34)	75 ± 63 (1-309)	395 ± 105 (174-584)
Eslamabad gharb	214 ± 76 (90-382)	163 ± 75 (18-315)	2 ± 4 (0-14)	102 ± 88 (2-421)	480 ± 129 (293-824)
Ilam	286 ± 96 (93-476)	179 ± 85 (27-324)	1 ± 4 (0-18)	116 ± 124 (2-519)	583 ± 174 (337-997)
Kangavar	164 ± 51 (71-270)	150 ± 64 (30-290)	3 ± 4 (0-17)	87 ± 76 (2-345)	404 ± 107 (222-662)
Kermanshah	174 ± 59 (57-307)	154 ± 70 (20-285)	2 ± 3 (0-14)	94 ± 80 (1-396)	424 ± 107 (216-703)
Khorramabad	215 ± 83 (91-385)	182 ±78 (48-385)	2 ± 3 (0-14)	91 ±79 (3-296)	490 ± 146 (271-835)
Koohrang	657 ± 233 (264-1197)	471 ± 198 (81-921)	3 ± 4 (0-18)	215 ± 158 (39-768)	1346 ± 374 (565-2040)
Mahabad	147 ± 54 (46-309)	162 ± 53 (57-303)	9 ± 9 (0-45)	86 ± 54 (8-203)	404 ± 101 (225-678)
Oroomieh airport	84 ± 32 (29-146)	134± 58 (37-304)	19 ± 18 (0-62)	71± 56 (7-221)	308 ± 92 (167-579)
Piranshahr	284 ± 119 (108-583)	252± 86 (83-472)	9 ± 10 (0-37)	128 ± 78 (22-330)	673 ± 186 (398-1121)
Ravansar	227 ± 74 (88-370)	189 ± 79 (31-347)	2 ± 4 (0-15)	106 ± 89 (1-361)	524 ± 128 (334-794)
Sad Dorudzan	279 ± 138 (81-668)	123 ± 65 (2-246)	1 ± 3 (0-13)	53± 53 (0-185)	458 ± 146 (159-848)
Saghez	164 ± 55 (92-323)	168± 63 (49-321)	13 ± 11 (0-40)	90 ± 71 (5-308)	437 ± 123 (273-791)
Sanandaj	146 ± 51 (56-278)	153 ± 59 33-312)(	4 ± 5 (0-22)	83 ± 62 (14-272)	385 ± 95 (236-645)
Sardasht	387 ± 150 (164-797)	299 ± 122 (103-597)	8 ± 8 (0-34)	151 ± 104 (8-388)	845 ± 210 (505-1255)
Sarpol-e zahab	219 ± 116 (75-584)	145 ± 79 (18-414)	0.7 ± 2 (0-8)	84 ± 71 (0-252)	435 ± 133 (250-950)
Shahr-e Kord	155 ± 65 (54-311)	111 ± 45 (14-229)	3 ± 6 (0-24)	50 ± 47 (2-189)	319± 93 (141-527)
Shiraz	201 ± 110 (58-556)	80 ± 47 (0-170)	2 ± 5 (0-25)	39 ± 39 (0-112)	322 ± 112 (97-622)
Takab	102 ± 34 (54-207)	140 ± 48 (33-216)	14 ± 13 (0-55)	66 ± 51 (1-202)	321 ± 86 (176-527)
Yasuj	457 ± 202 (137-974)	236 ± 116 (6-481)	4 ± 7 (0-31)	106 ± 105 (3-400)	803 ± 221 (294-1294)
Zagros region	237± 169 (29-1197)	183± 118 (0-921)	5± 9 (0-62)	95± 90 (0-768)	519± 287 (97-2040)

Table 5. The percentage of average seasonal precipitation (the amount of seasonal precipitation, mm) in the diverse climate types in the Zagros region of western.

Climate	Period	Winter	Spring	Summer	Autumn
Semi-dry	32-year period	43 (171)	37 (141)	1 (5)	19 (73)
	Before 2000	46 (188)	37 (148)	2 (6)	15 (65)
	After 2000	41 (159)	36 (137)	1 (5)	21 (79)
Mediterranean	32-year period	44 (222)	35 (174)	1 (5)	20 (103)
	Before 2000	45 (234)	37 (192)	1 (5)	16 (97)
	After 2000	43 (214)	34 (162)	1 (4)	22 (108)
Humid	32-year period	48 (446)	34 (314)	1 (6)	17 (150)
	Before 2000	49 (450)	35 (328)	1 (6)	15 (140)
	After 2000	48 (444)	34 (305)	1 (6)	18 (157)
Zagros region	32-year period	44 (237)	36 (183)	1 (5)	19 (95)
	Before 2000	47 (250)	37 (194)	1 (6)	15 (87)
	After 2000	43 (228)	35 (176)	1 (5)	21 (100)

We detected that the largest seasonal precipitation was different in diverse climate types. Precipitation pattern is complex due to the variation in elevation and latitude (Masoodian 1998). Moreover, the complex topography of the Zagros region is the driving force for distribution of seasonal precipitation (Modarres 2006). In the present study, most changes in seasonal precipitation after the initiation of oak decline were observed in the semi-dry and Mediterranean climates (Table 5). Modarres & da Silva (2007) reported that significant changes in the winter and spring precipitation trends were detected in the arid and semi-arid regions over Iran representing the seasonal shift of precipitation.

Classification of precipitation and event

Classification of annual precipitation and event into five classes in the Zagros region showed that 14%, 17%, 27%, 17% and 25% of precipitation events were less than 5 mm, 5-10 mm, 10-20 mm, 20-30 mm, and greater than 30 mm, respectively (Fig. 3). Over 50% of annual precipitation at Koohrang and Yasouj were larger than 30 mm, whereas less than 10% of annual precipitation in Yasouj, Sardasht, Sad Dorudzan, and Koohrang were less than 5 mm. Most stations recorded that 20-30% of annual precipitation ranged within 10 to 20 mm (Fig. 3, up). Approximately 60% of total annual events were than 5 mm, while only 5% of entire annual events were larger than 30 mm which was equal to those of class 20-30 mm (Fig. 3, lower). There was no significant change in the percentage of precipitation nor in the number of events that occurred in the different classes (Table 6). We detected that 60% of the total annual precipitation events in the Zagros region were smaller than 5 mm (14% of annual precipitation amount; Fig. 3). These values are also valid for before and after the starting oak decline phenomenon (Table 6). Only 5% of entire annual events were larger than 30 mm (25% of the total annual precipitation). No significant change was observed in the precipitation rate (%) and event number in diverse precipitation classes.

The Correlation between Precipitation and the Event Numbers

There was a wide range of the statistically significant correlation coefficients between annual precipitation and the number of events per year for twenty stations ranging from 0.50 in Koohrang to 0.79 in Sanandaj. On average, a significant correlation ($r = 0.68$; standard deviation = 0.08) between annual precipitation and the number of events per year using whole data in the Zagros region. Additionally, correlation coefficients were statistically significant before ($r = 0.72$) and after ($r = 0.65$) emerging the year of oak decline (2000) in the Zagros region (Table 7). We also examined the correlations between precipitation and the number of events per year in the semi-dry, Mediterranean, and humid climates (Table 7). All correlations were found to be statistically significant (Table 7). Correlation analysis showed that there was a positive significant correlation between precipitation events and the amount of precipitation across the Zagros region of western Iran ($r = 0.68$), i.e. an increase in the amount of precipitation was associated with an increase in the frequency of precipitation events. This was also true for the periods before and after the initiation of oak decline (Table 7). This suggests that more frequent rainfall does not result in a shift towards smaller events.

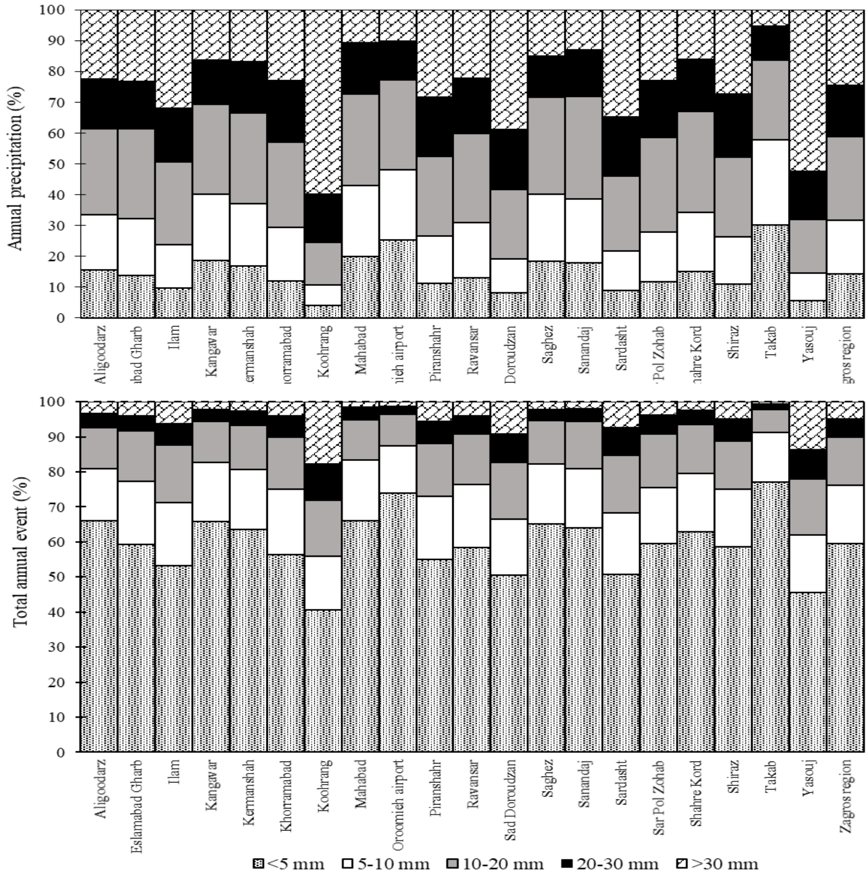

Fig. 3. Percentage of annual precipitation (upper) and number of annual events (lower) that had less than 5 mm, 5-10 mm, 10-20 mm, 20-30 mm, and higher than 30 mm during the 1988-2019.

Table 6. The percentage of precipitation and the number of events (in the parentheses) that fell into five classes of less than 5 mm, 5-10 mm, 10-20 mm, 20-30 mm, and more than 30 mm in the diverse climate types in the Zagros region, Western Iran. The values are from a 32-year period (1988-2019) and before and after the phenomenon of oak trees decline (the year 2000).

Climate	Period	<5 mm	5-10 mm	10-20 mm	20-30 mm	>30 mm
Semi-dry	32-year period	17 (64)	19 (16)	29 (13)	16 (4)	19 (3)
	Before 2000	17 (63)	19 (16)	29 (13)	17 (5)	17 (3)
	After 2000	17 (64)	19 (16)	28 (12)	16 (4)	20 (3)
Mediterranean	32-year period	14 (59)	18 (18)	29 (14)	16 (5)	23 (4)
	Before 2000	14 (58)	18 (18)	29 (15)	16 (5)	24 (4)
	After 2000	14 (59)	18 (17)	29 (14)	17 (5)	23 (4)
Humid	32-year period	8 (48)	11 (17)	20 (16)	17 (8)	44 (11)
	Before 2000	8 (48)	11 (17)	22 (17)	18 (8)	41 (10)
	After 2000	7 (48)	11 (17)	19 (15)	17 (8)	46 (12)
	32-year period	14 (60)	17 (17)	27 (13)	17 (5)	25 (5)
Zagros region	Before 2000	14 (59)	17 (17)	28 (14)	17 (5)	23 (5)
	After 2000	14 (60)	17 (17)	27 (13)	16 (5)	26 (5)

Table 7. The correlation coefficients (r) between precipitation and the number of events per year before and after the emerging oak decline phenomenon (2000) in different climate types of the Zagros region of Western Iran during 1988-2019.

Climate	Before 2000	After 2000	32-year period
Semi-dry	0.71	0.64	0.67
Mediterranean	0.78	0.70	0.71
Humid	0.68	0.64	0.65
Zagros region	0.72	0.65	0.68

Climate change may intensify the hydrological cycle by altering the amount of precipitation, the number of precipitation events, the event size, and the time between events (Knapp *et al.* 2015). These correlations, however, suggested that the number of events per year decreased in some years despite the increased annual precipitation, implying that the mean event size may have changed. However, the change in mean storm size was not significantly different for most locations (Table 2). It is Noteworthy that the increased small events will result in increased rate (%) of gross rainfall lost to interception loss by oak trees in the Zagros region, since canopies may not saturate during the rain events. Instead, the low through fall produced by oak trees during large events may result in flooding in this mountainous region. The main function of the Zagros forests is conservation of soil and water resources.

Future Research

The decline in oak trees does not appear to be directly linked to changes in precipitation. The previous research has suggested that other variables may be impacting oak health phenomenon (e.g. Doležal *et al*. 2010; Attarod *et al.* 2017). If precipitation has not dramatically changed but other variables, such as temperature has, the oak trees still experience the increased drought stress. The increase in temperature would the saturation vapor pressure and subsequently vapor pressure deficit. Future research should investigate other variables, such as temperature, on the overall weather, the oak trees are subjected to.

CONCLUSION

In general, precipitation has not changed significantly in the Zagros region. However, there was a general trend toward decreasing annual precipitation with 10% of the stations experiencing statistically significant decline from 1988 to 2018. The analysis revealed that winter precipitation decreased significantly during 1988 to 2018 at 35% of the sites. In addition to a trend of declining annual precipitation, there was also trend toward a decline in the winter (4%, 22 mm) and spring (2%, 18 mm) precipitation. In contrast, autumn precipitation increased (6%, 13 mm). If these trends strengthen, then this may have increased impacts on the forests. For the trends to become significant, longer timelines may be needed. When taken in conjunction with warming temperatures, these changes in the precipitation characteristics in the Zagros region during 1988–2019 strengthening ed the case for climate being partially responsible for oak decline. However, the analysis of addition meteorological data will provide more insight about the impact of climate change in this region. In the present study, we investigated if changes in precipitation are the sole reason for the decline in oak trees. Future work should focus the combined impacts of changes in precipitation and temperature as this will increase evaporative demand and may subsequently stress the oak trees.

ACKNOWLEDGMENTS

This research was financially supported by funding from Iran National Science Foundation (INSF) for the Joint Research Project number: 96001633.

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Bibliographic information of this paper for citing:

Attarod, P, Beiranvand, S, Pypker, TG, Bayramzadeh, V, Helali, J, Mashayekhi, Z, Fathi, J, Soofi Mariv, H 2023, Are precipitation characteristics and patterns impacting oak trees decline in the Zagros region of western Iran?. Caspian Journal of Environmental Sciences, 21: 753-765.