Change-point detection and trend analysis in monthly, seasonal and annual air temperature and precipitation series in Bartın province in the western Black Sea region of Turkey

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Abstract: Studies associated with climate change and variability are of great importance at both the global and local scale in the global climate crisis. In this study, change-point detection and trend analysis were carried out on mean, maximum, minimum air temperatures and total precipitation based on monthly, seasonal and annual scale in Bartın province located in the western Black Sea Region of Turkey. For this aim, 4-different homogeneity tests (von Neumann test, Pettitt test, Buishand range test and standard normal homogeneity test) for change-point detection, Modified Mann–Kendall test and Şen's innovative trend test for trend analysis, and Sen's slope test for the magnitude estimation of trends were used. According to the test results, the summer temperatures in particular show increasing trends at the 0.001 significance level. Mean maximum temperature in August, mean minimum temperature in June and August, and mean temperature in July and August are in increasing trend at the 0.001 significance level. Over a 51 year period (1965–2015) in Bartın province, the highest rate of change per decade in air temperatures is in August (0.55°C for T_{max}, 0.46°C for T_{min} and 0.43°C for T_{mean}) based on Sen's slope. However, the study showed that apart from October precipitation, there is no significant trend in monthly, seasonal and annual precipitation in Bartın. Increasing trends in mentioned climate variables are also visually very clear and strong in Şen's innovative trend method, and they comply with the statistical results. As a result, the study revealed some evidence that temperatures will increase in the future in Bartın and its environs.

Keywords: climate change, homogeneity, precipitation, temperature, trend analysis

INTRODUCTION

Based on IPCC's reports (IPCC 2014, IPCC 2018), we know that global climate change is a reality. IPCC (2014) declared the globally averaged combined land and ocean surface temperature data imply a warming of 0.85 ±0.20°C in the period 1880 to 2012. It's estimated that this warming increase will probably reach 1.5°C between 2030 and 2052 if it continues to extend at this rate (IPCC 2018). In recent years, considerable attention has been dedicated to studies associated with climate variability and global climate change (Türkeş et al. 1995, 1996, 2002, Dabanlı 2018, Mahmood et al. 2019, Türkeş 2019, Ay 2020, Sönmez & Kale 2020, Patakamuri et al. 2020). Due to the negative impacts of global climate change on ecosystems, agriculture, forestry, food and water supply, health etc, the studies associated with climate change are of great importance at the global, regional and local scales. Located in the Eastern Mediterranean basin, Turkey is considered to be adversely affected by the consequences of climate change (Önder et al. 2009, Tayanç et al. 2009, Türkeş & Tatlı 2009, Önol & Unal 2012, Demircan et al. 2014, 2017, Önol et al. 2014, Dabanlı 2018). The different climate variables of Bartın province have been investigated from various perspectives at both the regional and local scale (Ertuğrul et al. 2014, Turoğlu 2014, Bolat et al. 2018, Şensoy & Ateşoğlu 2018, Yozgatlıgil & Türkeş 2018, Balov & Altunkaynak 2019, Ay 2020, Cengiz et al. 2020, Sönmez & Kale 2020, Yaman et al. 2020). Ertuğrul et al. (2014) evaluated whether the indication of climate change in Bartın's forests is occuring, based on the Standard Precipitation Index (SPI). Using the temperature and precipitation data for the period 1965–2012 in Bartın, Turoğlu (2014) carried out climate analysis based on Thornthwaite and De Martonne's methods. Şensoy & Ateşoğlu (2018) researched the type of climate change occurring in Bartın using the Thornthwaite method and 5-year averages of climate variables. Based on the arithmetic averages for the periods 1980–1999 and 2000–2015 without a statistical significance test, Bolat et al. (2018) investigated the temperature (minimum, maximum and mean) and precipitation (maximum and total) values in Bartın province. Yozgatlıgil & Türkeş (2018) analysed the monthly maximum precipitation series and forecasted the maximum precipitation amount using a probabilistic approach and multivariate time series analysis in the western Black Sea region, also including Amasra and Bartın. Balov & Altunkaynak (2019) studied extreme precipitation indices based on outputs of global circulation models in the western Black Sea region, also including Bartın province. Ay (2020) carried out homogeneity and trend tests on the time series of monthly mean temperature and monthly total precipitation recorded in Düzce, Bolu, Zonguldak, Bartın, Kastamonu and Sinop provinces in the western Black Sea region of Turkey. Cengiz et al. (2020) researched historical precipitation change using both graphical and statistical methods in the provinces of the Black Sea Region of Turkey. In a study on the annual streamflow of Filyos River, Sönmez & Kale (2018) used some climate variables of Bartın province. Yaman et al. (2020) investigated the relationships between tree-ring growth of oriental beech and climate variables in Abdipaşa, Bartın, and they also focused on the Streamflow Drought Index (SDI) of the Kocaırmak River in the same basin.

Based on many regional climate studies related to Turkey, we know that Turkey's different regions from South to North and West to East are affected differently by climate change. However, the effects of climate change on a local scale in a region are relatively less well-known. Therefore, we have focused on Bartın province in the western Black Sea coast since its climate data is available. In the present study, using monthly, seasonal and annual minimum, maximum and mean air temperature values and precipitation amounts observed in Bartın Meteorological Station in the period 1965–2015, change point detection and trend analysis have been carried out, and the rates of changes per decade in the climate variables in question have been estimated. Also, results have been evaluated based on climate variability/change.

MATERIAL AND METHOD

Data

Bartın province, located in the western Black Sea region of Turkey, has been selected for change detection and trend assessment of its historical climate variables (Fig. 1). The climate variables investigated are mean maximum air temperature (T_{max}), mean minimum air temperature (T_{min}), mean air temperature (T_{mean}) and total precipitation (P_{tot}). In terms of change detection and trend assessment, all of the climate variables were investigated at a monthly, seasonal and annual scale. A total of 68-time series belonging to climate variables were investigated for homogeneity, change-point and trend analysis. For all climate variables, 51-year meteorological data (the period 1965–2015) were used in the analyses, and they were obtained from the Turkish State Meteorological Service. The geographical coordinates of the Bartın Meteorological Station are 41°37'29.00" N, 32°21'24.53" E, 33 m a.s.l. Based on the Walter climate diagram of Bartın province (Yaman et al. 2020), it concludes that the precipitation line is over the temperature line for all months, and a dry period is not present in Bartın. Bartın's climate is humid, with a total precipitation of 1047 mm·year^{-1}. The wettest season in Bartın is winter (336.2 mm·year^{-1}), followed by autumn (309.4 mm·year^{-1}), summer (211.2 mm·year^{-1}) and spring (190.3 mm·year^{-1}) respectively (Akman 2011). Based on the Johansson Continentality Index, it can be said that Bartın province has an oceanic climate (Toros et al. 2008).

Fig. 1. *The grey shaded area shows Bartın province in the western Black Sea region of Turkey*

Homogeneity and change-point analysis

In the analysis, different statistical tests were applied to climatological variables for change point detection and trend analysis. Determining the change point of a time series is an important aspect of climate investigations (Patil 2019). Since the different homogeneity tests might show different results for the same time series, multiple methods are used instead of a single method for detecting change point in a time series (Jaiswal et al. 2015). Pettitt's test (Pettitt 1979, Rybski & Neumann 2011), Buishand range test (Buishand 1982), standard normal homogeneity test (Alexandersson 1986) and von Neumann test (von Neumann 1941) have been commonly used for change point detection (Tarhule & Woo 1998, Wijngaard et al. 2003, Gao et al. 2011, Kang & Yusof 2012, Li et al. 2014, Xie et al. 2014, Jaiswal et al. 2015, Kocsis et al. 2020). While the statistics of Pettitt's test, Buishand range test and standard normal homogeneity test were estimated using the trend package (version: 1.1.2) in R (Pohlert 2020), the climtrends v1.0.6 package was used for the von Neumann ratio test (Gama 2016). To decide whether there is any significant change point in the time series of the climatical variables investigated, in this study the results of the four tests mentioned above were evaluated together (Wijngaard et al. 2003, Jaiswal et al. 2015).

In this context, 1. if three of four tests reject the null hypothesis at a 5% significant level, a series is considered as inhomogeneous (there is a change-point (CP)), 2. if three of four tests do not reject the null hypothesis at a 5% significant level, a series is considered homogeneous (there is no change-point (HG)), and 3. if only two of four tests reject/don't reject the null hypothesis at a 5% significant level, a series is considered to be a doubtful series (DF) and such a series should be investigated in detail before further analysis (Jaiswal et al. 2015).

Trend analysis

The non-parametric Mann–Kendall test (MK) is commonly used to detect monotonic trends in a series of climate data or hydrological data (Mitchell et al. 1971, Jaiswal et al. 2015, Mahmood et al. 2019, Patil 2019). Using the historical data from 1965 to 2015 observed in Bartın Meteorological Station, the Mann–Kendall test was used to identify statistically significant trends in the aforementioned climatological variables. This test does not require the data to have a normal distribution and has low sensitivity to abrupt breaks due to the inhomogeneous time series (Jaiswal et al. 2015). However, since serial correlation can mislead the actual result of the trends, the serial correlation must be removed from a time series (Hamed & Rao 1998, Yue et al. 2002). For this, before the application of the Mann–Kendall test, the Trend-Free Pre-Whitening method (TFPW) was used in the present study (Mahmood et al. 2019). Besides, to estimate the magnitude of detected trends, Sen's slope method was applied in the study (Sen 1968, Jaiswal et al. 2015, Mahmood et al. 2019).

The modified mk package (version 1.5.0) in R was used for the Mann–Kendall trend test applied to the Trend-Free Prewhitened Time Series Data in the presence of serial correlation (Patakamuri & O'Brien 2020). The tfpwmk(x) in the package calculates the following: Z statistic after trend-free prewhitening (TFPW), Sen's slope for TFPW series, Sen's slope for original data series (x), P-value after trend-free prewhitening, Mann–Kendall S statistic, Variance of S and Mann–Kendall's Tau (Patakamuri & O'Brien 2020).

In the present study, as well as the Mann–Kendall trend test, Şen's innovative trend analysis (Şen 2012), a relatively new method, was applied to time series having statistically significant trends according to Mann–Kendall test results. In this method, subsection time series derived from a given time series plot on a Cartesian coordinate system. Herein, trend free time-series appear along the 1:1 (45°) straight line. Increasing/decreasing trends are plotted in the upper/lower triangular areas of the square area defined by the variation domain of the variable concerned (Şen 2012). This method shows non-monotonic trends as well as monotonic trends (Dabanlı et al. 2016) and does not require any assumption, meaning that sample size and whether serial correlation and non-normal distribution in a time series are present are not important (Şen 2012, Dabanlı et al. 2016).

RESULTS (Figs. 2–5, Tabs. 1–4)

Maximum temperature (T_{max})

Related to T_{max}, the results of the four different homogeneity tests and the Mann–Kendall trend test are shown in Table 1. In terms of this climate variable, while the time series belonging to July, August and September, the seasons of summer and autumn, and the annual period are inhomogeneous, the others are homogeneous. Homogeneity tests indicated statistically significant change points in the year of 1997 for all inhomogeneous time series mentioned above except for autumn. The year 1999 has a change point in autumn. Modified Mann–Kendall test showed statistically significant increasing trends in July T_{max} ($z = 2.99$, $p < 0.01$), August T_{max} ($z = 3.75$, $p < 0.001$) and September T_{max} ($z = 2.34$, $p < 0.05$), the T_{max} of summer ($z = 3.78$, $p < 0.001$) and autumn ($z = 2.06$, $p < 0.05$), and annual T_{max} ($z = 2.63$, $p < 0.01$). Sen's slope showing the magnitude of the increase/decrease in the trend changes from 0.023 to 0.055, so the highest Sen's slope value is found in August T_{max}.

Şen's innovative trend analysis was also carried out and its results plotted for statistically significant months and periods based on the results of the Mann–Kendall trend test (Fig. 2A–F). Similar to the results of the Mann–Kendall trend test, this innovative visual method also indicated increasing trends for monthly, seasonal and annual T_{max} mentioned above. Increasing trends are very clear and particularly strong in August T_{max} and summer T_{max} (Fig. 2B, D).

Minimum temperature (T_{min})

Related to T_{min}, the results of the homogeneity tests and Mann–Kendall trend test are shown in Table 2. In terms of this climate variable, while the time series belonging to June, July, August, September, the season of summer, and annual period are inhomogeneous, the others are homogeneous. Homogeneity tests indicated statistically significant change points in the years 1990 (for August T_{min}), 1994 (for July T_{min} and summer T_{min}), 1996 (for June T_{min}) and 1997 (for September T_{min} and annual T_{min}) for all inhomogeneous time series.

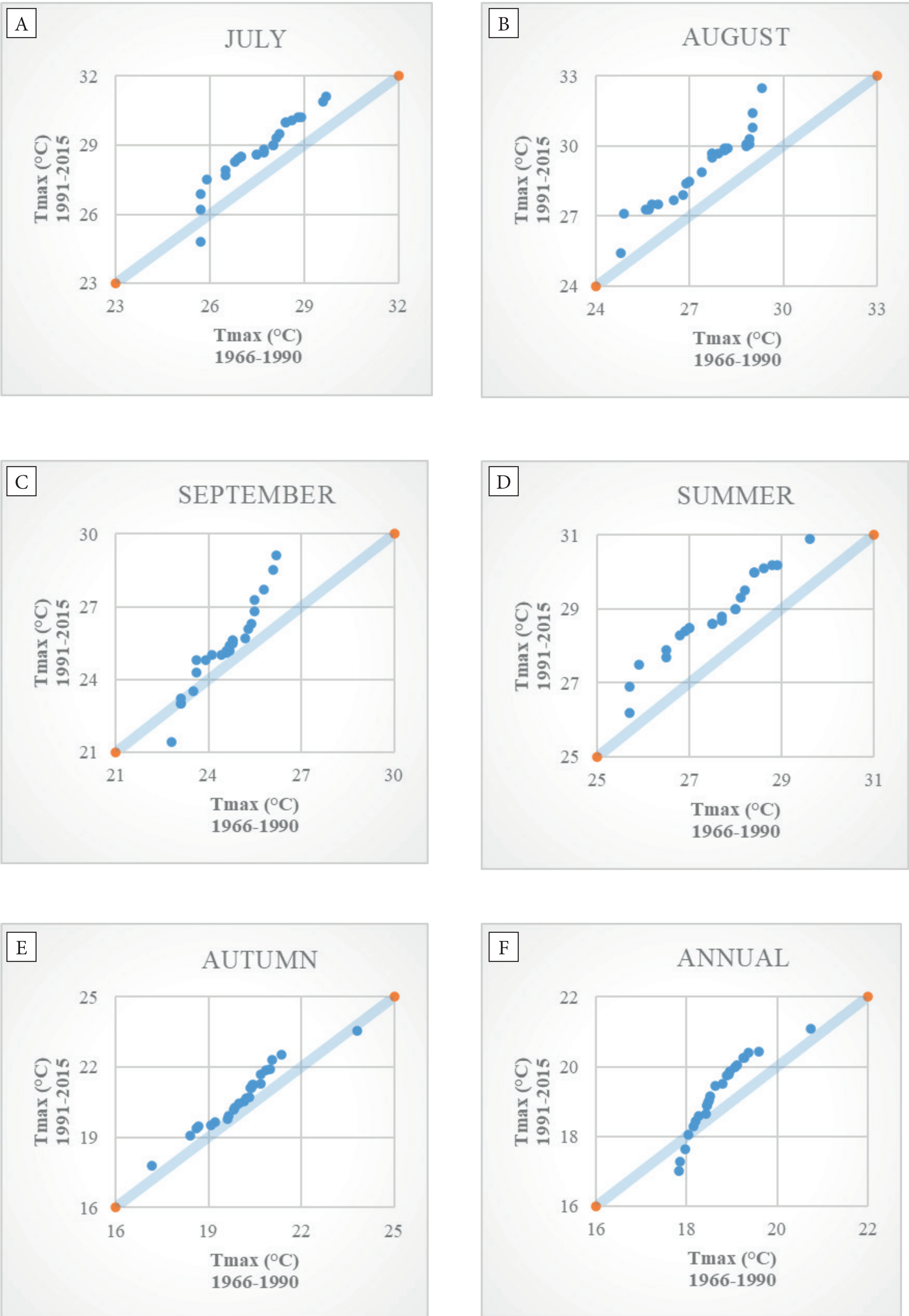

Fig. 2. *Şen's innovative trend analysis results for maximum temperature*

Table 1. *The results of four different homogeneity tests and Mann–Kendall test for maximum temperature*

Period	Pettitt test			Buishand range test			SNH test			von Neuman test		Final results		Mann–Kendall test			
	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Nature	Year of shift	Z-Value	Sen slope	Signifi-cance	Trend
January	176	No	–	1.21	No	–	3.63	No	–	2.17	No	HG	–	1.25	–	$p > 0.05$	No
February	118	No	–	1.13	No	–	2.92	No	–	1.81	No	HG	–	0.03	–	$p > 0.05$	No
March	162	No	–	1,10	No	–	3.37	No	–	1.90	No	HG	–	0.40	–	$p > 0.05$	No
April	113	No	–	0.77	No	–	2.78	No	–	2.51	No	HG	–	0.28	–	$p > 0.05$	No
May	254	No	–	1.46	No	–	5.88	No	–	1.56	No	HG	–	1.29	–	$p > 0.05$	No
June	226	No	–	1.42	No	–	9.56	Yes	2006	1.38	Yes	DF	–	1.15	–	$p > 0.05$	No
July	458	Yes	1997	2.19	Yes	1995	18.84	Yes	1997	1.20	Yes	CP	1997	2.99	0.041	$p < 0.01$	Yes +
August	409	Yes	1997	1.96	Yes	1997	16.87	Yes	1997	1.71	No	CP	1997	3.75	0.055	$p < 0.001$	Yes +
September	331	Yes	1997	1.56	Yes	1997	9.98	Yes	2009	1.63	No	CP	1997	2.34	0.029	$p < 0.05$	Yes +
October	198	No	–	1.05	No	–	2.51	No	–	1.63	No	HG	–	0.95	–	$p > 0.05$	No
November	177	No	–	1.49	No	–	4.09	No	–	1.88	No	HG	–	0.30	–	$p > 0.05$	No
December	191	No	–	1.46	No	–	6.39	No	–	1.51	Yes	HG	–	1.10	–	$p > 0.05$	No
Spring	212	No	–	1.25	No	–	5.06	No	–	1.91	No	HG	–	0.74	–	$p > 0.05$	No
Summer	494	Yes	1997	2.32	Yes	1997	23.60	Yes	1997	1.12	Yes	CP	1997	3.78	0.037	$p < 0.001$	Yes +
Autumn	320	Yes	1999	1.84	Yes	1999	10.28	Yes	2006	1.80	No	CP	1999	2.06	0.025	$p < 0.05$	Yes +
Winter	214	No	–	1.50	No	–	7.69	No	–	1.78	No	HG	–	1.07	–	$p > 0.05$	No
Annual	425	Yes	1997	2.15	Yes	1997	18.28	Yes	2006	1.08	Yes	CP	1997	2.63	0.023	$p < 0.01$	Yes +

HG – homogeneous, CP – inhomogeneous (change point), DF – doubtful, "+" – increasing trend.

Table 2. *The results of four different homogeneity tests and Mann–Kendall test for minimum temperature*

Period	Pettitt test			Buishand range test			SNH test			von Neuman test		Final results		Mann–Kendall test			
	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Nature	Year of shift	Z-Value	Sen slope	Signifi-cance	Trend
January	151	No	–	1.23	No	–	2.73	No	–	2.02	No	HG	–	0.89	–	$p > 0.05$	No
February	154	No	–	1.34	No	–	2.88	No	–	1.87	No	HG	–	−0.31	–	$p > 0.05$	No
March	155	No	–	1.07	No	–	2.38	No	–	1.89	No	HG	–	0.52	–	$p > 0.05$	No
April	135	No	–	0.90	No	–	3.64	No	–	2.06	No	HG	–	−0.33	–	$p > 0.05$	No
May	183	No	–	1.31	No	–	7.40	No	–	1.66	No	HG	–	1.00	–	$p > 0.05$	No
June	357	Yes	1996	1.74	Yes	1996	11.37	Yes	1996	1.83	No	CP	1996	3.41	0.045	$p < 0.001$	Yes +
July	357	Yes	1994	1.75	Yes	1994	12.05	Yes	1994	1.69	No	CP	1994	2.96	0.044	$p < 0.01$	Yes +
August	436	Yes	1990	2.08	Yes	1990	17.45	Yes	1997	1.62	No	CP	1990	3.45	0.046	$p < 0.001$	Yes +
September	414	Yes	1997	1.87	Yes	1997	15.31	Yes	1997	1.14	Yes	CP	1997	3.19	0.040	$p < 0.01$	Yes +
October	270	No	–	1.32	No	–	6.93	No	–	1.75	No	HG	–	2.06	0.031	$p < 0.05$	DF
November	151	No	–	1.01	No	–	3.24	No	–	1.97	No	HG	–	−0.05	–	$p > 0.05$	No
December	151	No	–	0.77	No	–	5.07	No	–	2.05	No	HG	–	−0.79	–	$p > 0.05$	No
Spring	128	No	–	1.22	No	–	2.94	No	–	1.98	No	HG	–	0.38	–	$p > 0.05$	No
Summer	471	Yes	1994	2.14	Yes	1994	19.07	Yes	1996	1.37	Yes	CP	1994	4.22	0.043	$p < 0.001$	Yes +
Autumn	365	Yes	1997	1.43	No	–	8.84	Yes	1997	1.75	No	DF	–	2.19	0.027	$p < 0.05$	DF
Winter	166	No	–	1.07	No	–	3.67	No	–	1.73	No	HG	–	−0.35	–	$p > 0.05$	No
Annual	359	Yes	1997	1.97	Yes	1997	12.39	Yes	1997	1.58	No	CP	1997	2.40	0.016	$p < 0.05$	Yes +

HG – homogeneous, CP – inhomogeneous (change point), DF – doubtful, "+" – increasing trend.

Table 3. *The results of four different homogeneity tests and Mann–Kendall test for mean temperature*

Period	Pettitt test			Buishand range test			SNH test			von Neuman test		Final results		Mann–Kendall test			
	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Nature	Year of shift	Z-Value	Sen slope	Signifi-cance	Trend
January	118	No	–	1.13	No	–	2.38	No	–	2.18	No	HG	–	0.67	–	$p > 0.05$	No
February	134	No	–	1.15	No	–	2.46	No	–	1.82	No	HG	–	−0.17	–	$p > 0.05$	No
March	162	No	–	1.20	No	–	2.77	No	–	1.94	No	HG	–	0.32	–	$p > 0.05$	No
April	103	No	–	0.81	No	–	2.25	No	–	2.33	No	HG	–	−0.70	–	$p > 0.05$	No
May	152	No	–	1.31	No	–	3.12	No	–	1.49	Yes	HG	–	0.27	–	$p > 0.05$	No
June	307	Yes	1996	1.64	Yes	2005	13.05	Yes	2005	1.75	No	CP	2005	2.68	0.023	$p < 0.01$	Yes +
July	446	Yes	1995	2.15	Yes	1995	18.28	Yes	1997	1.31	Yes	CP	1995	3.35	0.036	$p < 0.001$	Yes +
August	405	Yes	1997	1.98	Yes	1997	17.12	Yes	1997	1.72	No	CP	1997	3.36	0.043	$p < 0.001$	Yes +
September	386	Yes	1997	1,79	Yes	1997	11.63	Yes	1997	1.55	No	CP	1997	2.12	0.020	$p < 0.05$	Yes +
October	226	No	–	1.05	No	–	3.32	No	–	1.62	No	HG	–	1.02	–	$p > 0.05$	No
November	173	No	–	1.16	No	–	5.44	No	–	1.88	No	HG	–	−0.32	–	$p > 0.05$	No
December	166	No	–	1.02	No	–	7.10	No	–	1.71	No	HG	–	−0.02	–	$p > 0.05$	No
Spring	131	No	–	1.20	No	–	2.55	No	–	1.88	No	HG	–	−0.13	–	$p > 0.05$	No
Summer	515	Yes	1997	2.44	Yes	1997	25.62	Yes	1997	1.13	Yes	CP	1997	3.95	0.032	$p < 0.001$	Yes +
Autumn	321	Yes	1997	1.72	Yes	1997	6.93	No	–	1.79	No	DF	–	1.40	–	$p > 0.05$	No
Winter	145	No	–	1.19	No	–	4.06	No	–	1.68	No	HG	–	−0.15	–	$p > 0.05$	No
Annual	353	Yes	1997	2.09	Yes	1997	10.46	Yes	1997	1.43	Yes	CP	1997	1.81	–	$p > 0.05$	No

HG – homogeneous, CP – inhomogeneous (change point), DF – doubtful, "+" – increasing trend.

Table 4. *The results of four different homogeneity tests and Mann–Kendall test for precipitation*

Period	Pettitt test			Buishand range test			SNH test			von Neuman test		Final results		Mann–Kendall test			
	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Year of shift	Statistic	Shift	Nature	Year of shift	Z-Value	Sen slope	Signifi-cance	Trend
January	152	No	–	1.21	No	–	6.37	No	–	1.99	No	HG	–	0.07	–	$p > 0.05$	No
February	130	No	–	1.20	No	–	3.22	No	–	2.24	No	HG	–	−0.12	–	$p > 0.05$	No
March	302	Yes	1994	1.67	Yes	1994	8.47	Yes	2007	1.59	No	CP	1994	1.51	–	$p > 0.05$	No
April	152	No	–	0.93	No	–	8.06	No	–	1.99	No	HG	–	−0.85	–	$p > 0.05$	No
May	208	No	–	1.07	No	–	3.99	No	–	1.89	No	HG	–	−0.94	–	$p > 0.05$	No
June	236	No	–	1.49	No	–	6.77	No	–	1.90	No	HG	–	1.12	–	$p > 0.05$	No
July	162	No	–	0.99	No	–	3.14	No	–	1.84	No	HG	–	0.62	–	$p > 0.05$	No
August	255	No	–	1.03	No	–	4.16	No	–	2.14	No	HG	–	−1.59	–	$p > 0.05$	No
September	307	Yes	1988	1.57	Yes	1988	7.32	No	–	1.50	Yes	CP	1988	1.47	–	$p > 0.05$	No
October	249	No	–	1.19	No	–	7.07	No	–	2.20	No	HG	–	2.01	1.389	$p < 0.05$	DF
November	152	No	–	0.73	No		3.81	No	–	1.96	No	HG	–	0.10	–	$p > 0.05$	No
December	226	No	–	1.10	No	–	5.14	No	–	2.22	No	HG	–	−1.22	–	$p > 0.05$	No
Spring	232	No	–	1.53	No	–	5.29	No	–	1.90	No	HG	–	−0.25	–	$p > 0.05$	No
Summer	116	No	–	1.08	No	–	1.82	No	–	2.64	No	HG	–	0.72	–	$p > 0.05$	No
Autumn	326	Yes	1987	1.52	No	–	8.19	No	–	1.61	No	HG	–	1.66	–	$p > 0.05$	No
Winter	226	No	–	1.26	No	–	8.03	No	–	2.15	No	HG	–	−0.87	–	$p > 0.05$	No
Annual	180	No	–	1.35	No	–	3.54	No	–	2.23	No	HG	–	0.64	–	$p > 0.05$	No

HG – homogeneous, CP – inhomogeneous (change point), DF – doubtful, "+" – increasing trend.

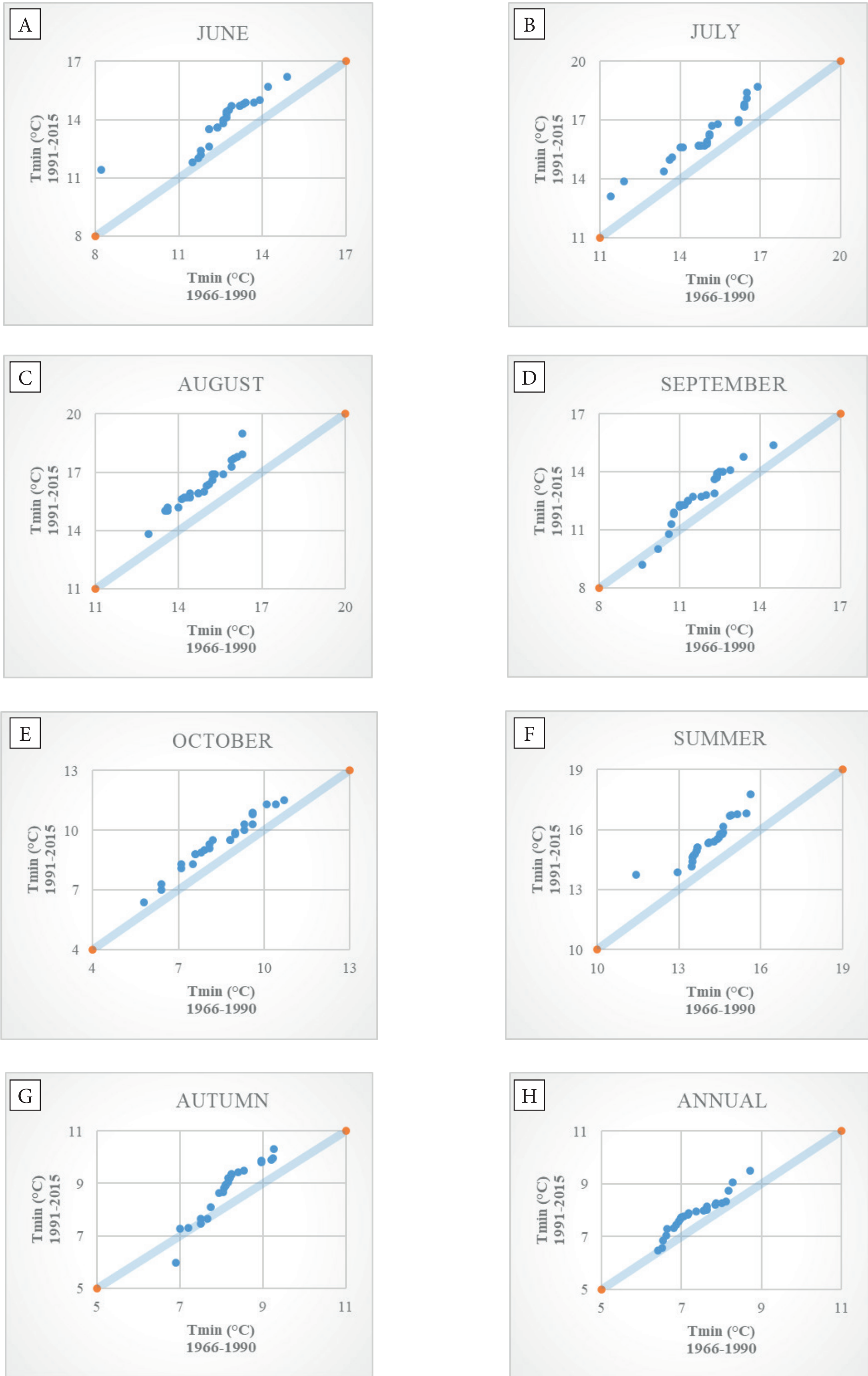

***Fig. 3.** Şen's innovative trend analysis results for minimum temperature*

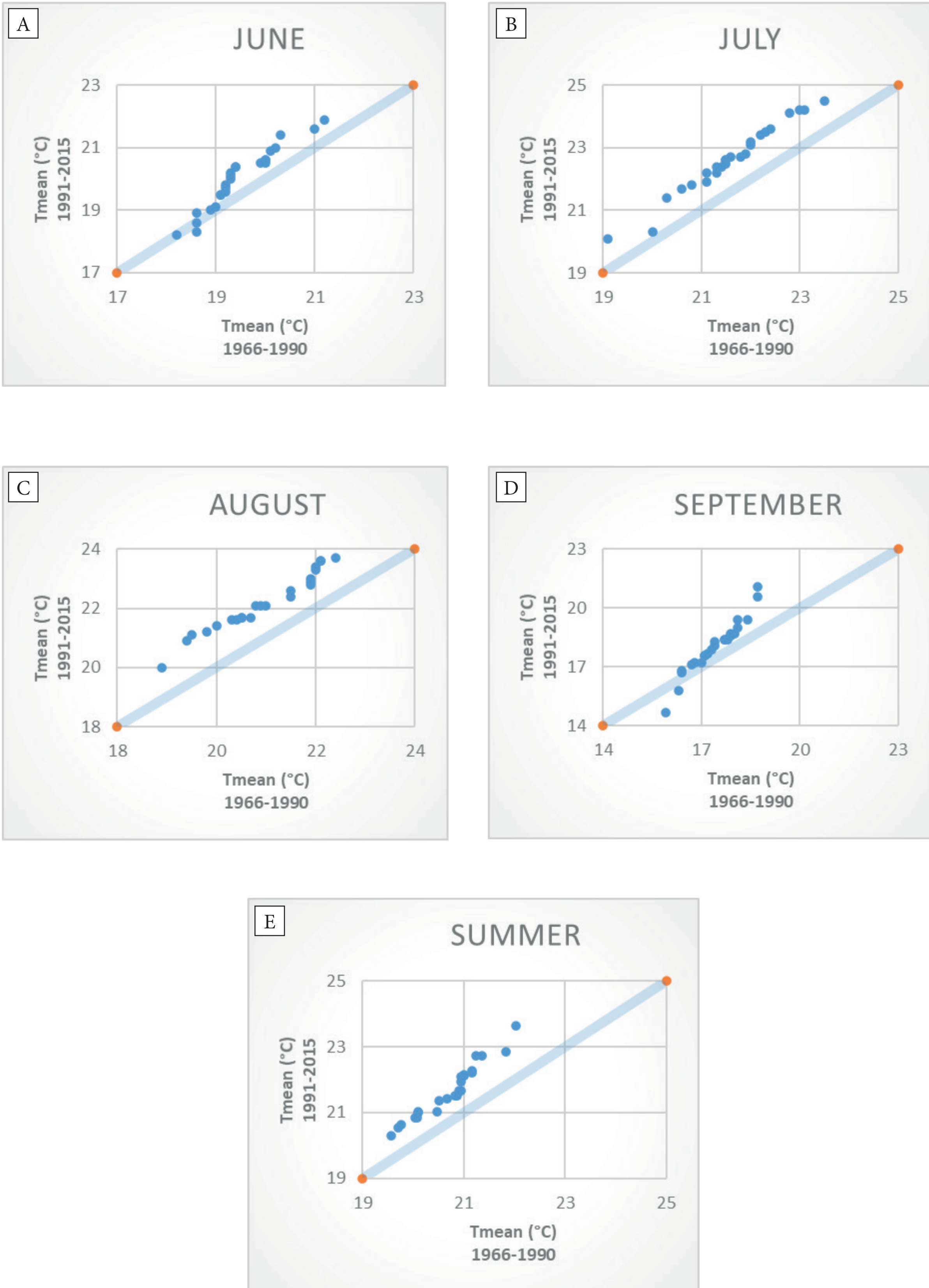

Fig. 4. *Şen's innovative trend analysis results for mean temperature*

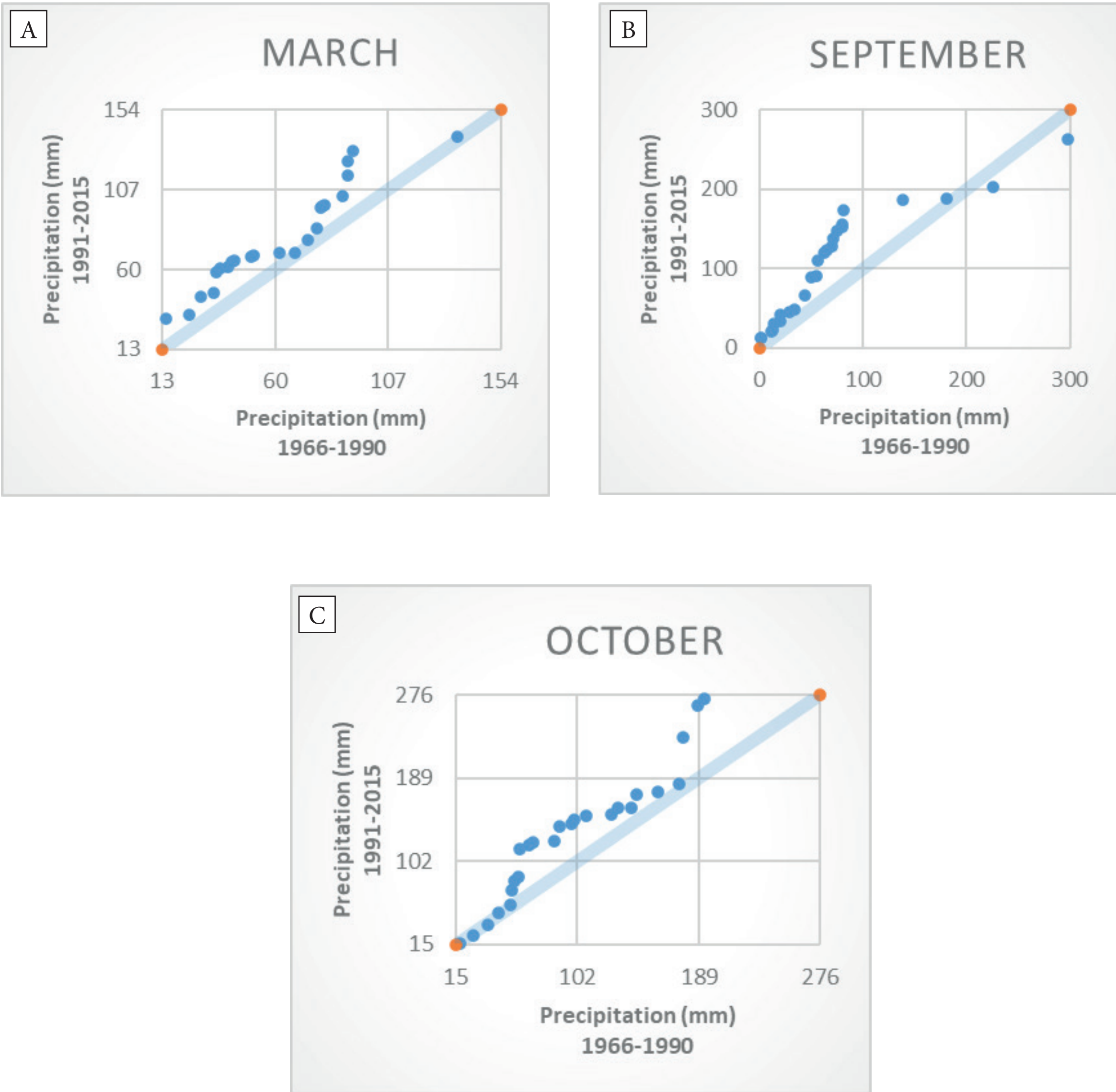

Fig. 5. *Şen's innovative trend analysis results for precipitation*

Modified Mann–Kendall test showed statistically significant increasing trends in June T_{min} (z = 3.41, p < 0.001), July T_{min} (z = 2.96, p < 0.01), August T_{min} (z = 3.45, p < 0.001), September T_{min} (z = 3.19, p < 0.01), summer T_{min} (z = 4.22, p < 0.001), and annual T_{min} (z = 2.40, p < 0.05). Despite being a homogeneous time series, October T_{min} shows a significant trend (but doubtful) (z = 2.06, p < 0.05). Moreover, in terms of homogeneity, autumn T_{min} is a doubtful time series (DF), but it shows a significant trend (z = 2.19, p < 0.05). Sen's slope changes from 0.016 to 0.046, so the highest Sen's slope value is found in August T_{min}. Şen's innovative trend analysis was also carried out and its results plotted for statistically significant months and periods based on the results of the Mann–Kendall trend test (Fig. 3A–H). Similar to the results of the Mann–Kendall trend test, this innovative visual method also indicated increasing trends for monthly, seasonal and annual T_{min} mentioned above. Increasing trends are very clear and strong in particularly June, July, August and summer (Fig. 3A–C, F). Although showing a homogeneous time series in the homogeneity tests, October T_{min} displays a clear increasing trend in Şen's innovative trend analysis, like the Mann–Kendall test (Fig. 3E).

Mean temperature (T_{mean})

Related to T_{mean}, the results of the homogeneity tests and Mann–Kendall trend test are shown in Table 3. In terms of this climate variable, while the time series belonging to June, July, August, September, the season of summer, and annual period are inhomogeneous, the others are homogeneous. Homogeneity tests indicated statistically significant change points in the years 1995 (for July T_{mean}), 1997 (for August T_{mean}, September T_{mean}, summer T_{mean} and annual T_{mean}) and 2005 (for June T_{mean}) for all inhomogeneous time series. Modified Mann–Kendall test showed statistically significant increasing trends in June T_{mean} ($z = 2.68$, $p < 0.01$), July T_{mean} ($z = 3.35$, $p < 0.001$), August T_{mean} ($z = 3.36$, $p < 0.001$), September T_{mean} ($z = 2.12$, $p < 0.05$) and summer T_{mean} ($z = 3.95$, $p < 0.001$). Despite being an inhomogeneous time series, annual T_{mean} didn't show a significant trend ($z = 1.81$, $p > 0.05$). Sen's slope changes from 0.020 to 0.043, so the highest Sen's slope value is found in August T_{mean}.

Şen's innovative trend analysis was also carried out and its results plotted for statistically significant months and periods based on the results of the Mann–Kendall trend test (Fig. 4A–E). Similar to the results of the Mann–Kendall trend test, this innovative visual method also indicated increasing trends for monthly and seasonal T_{mean} mentioned above. Increasing trends are very clear and particularly strong in July, August and summer (Fig. 4B, C, E).

Total precipitation (P_{tot})

In terms of P_{tot}, only the time series belonging to March and September are inhomogeneous, but the Mann–Kendall trend test did not indicate any significant trend for the two months (Tab. 4). However, Şen's innovative trend analysis displays a partially increasing trend in March P_{tot} while no trend in September P_{tot} (Fig. 5A, B). Moreover, despite being a homogeneous series, October P_{tot} shows an increasing trend based on the Mann–Kendall test ($z = 2.01$, $p < 0.05$). October P_{tot} also displays an increasing trend in Şen's innovative trend analysis (Fig. 5C).

DISCUSSION

This study focused on change-point detection and the trend analysis of mean, maximum, minimum air temperatures and total precipitation based on monthly, seasonal and annual scale in Bartın located in the western Black Sea region of Turkey. To this end, four different homogeneity tests (von Neumann 1941, Pettitt 1979, Buishand 1982, Alexandersson 1986) for change-point detection, modified Mann–Kendall test (Hamed & Rao 1998, Patakamuri & O'Brien 2020) and Şen's innovative trend test (Şen 2012, Dabanlı et al. 2016) for trend analysis, and Sen's slope test (Sen 1968, Patakamuri & O'Brien 2020) for the magnitude estimation of trends were used. When the results are evaluated together, particularly the temperatures of the summer season show increasing trends at a 0.001 significance level. Mean maximum temperature in August, mean minimum temperature in June and August, and mean temperature in July and August are an increasing trend at 0.001 significance level (Tabs. 1–3).

For the months and climatological variables mentioned above, according to the results of Şen's innovative trend test, increasing trends are also visually very clear and strong (Figs. 2B, 3A, C, 4B, C). In many studies at different times, long term trends and changes in Turkey's climate have been analysed using the monthly mean, monthly mean maximum and monthly mean minimum air temperature data (°C) recorded in the stations of the General Directorate of Meteorology (MGM) (Türkeş et al. 1995, 1996, 2002, Türkeş 2019). Türkeş et al. (1995) concluded that the long-term annual mean air temperatures in the period of 1930–1992 are generally dominated by a decreasing tendency in Turkey. Then, based on a re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929–1999, Türkeş et al. (2002) indicated summer and particularly autumn mean temperatures have decreased over the northern and continental inner regions of Turkey. In the same paper, they explained that maximum temperatures (for winter, spring, summer and annual) have shown an increasing trend at many stations, except those in the Central Anatolia, Black Sea, and partly Eastern Anatolia regions.

The recent study of Türkeş (2019) has concluded that there are increasing trends particularly in the summer and autumn temperatures of Turkey, and these warming temperatures are gradually strengthening. Despite the weak warming temperatures throughout the Black Sea region (Türkeş 2019), the present study indicates statistically significant increasing trends for T_{max}, T_{mean} and T_{min} in summer (particularly in August) in Bartın province located in the western Black Sea region. Based on the change point analysis of the temperature time series investigated, it can be concluded that the climate change point is mainly in the 1990s (especially in 1997). For the time series (1960–2017) of monthly mean temperature and monthly total precipitation recorded in the provinces (also including Bartın) in the western Black Sea region of Turkey, Ay (2020) indicated there are no statistically significant trends in all stations according to the Mann–Kendall trend test. However, he stated there are statistically significant increasing trends for monthly mean temperature in all stations according to Şen's innovative trend method. Şensoy & Ateşoğlu (2018) investigated whether there have been any changes in the climate type present in the Bartın province based on Thornthwaite's method. The authors stated that even if the alteration presents itself in some indices, climate type change did not occur in the period 1965–2014 in Bartın province. However, they stated that the mean annual temperature and summer temperature is 1.8°C and 2.06°C higher respectively in the last two decades of this period. Compared to the southern part of Turkey, Ertugrul (2019) also found greater changes in the climate data of the Black Sea region of Turkey, and he warned about forest fire risk for the same region in the future. Cengiz et al. (2020) analyzed the historical precipitation changes at 16 stations (also including Bartın) during 1960–2015 in the Black Sea region of Turkey using two different graphical methods. The authors stated that in Bartın province while there is no seasonal trend for a full-time series, there are statistically significant trends for the first half sub-series of spring and second half sub-series of autumn (–3.54 mm·year^{-1} and 6.47 mm·year^{-1} respectively). The present study showed that apart from October precipitation, there is no significant trend in monthly, seasonal and annual precipitation in Bartın province. Despite there being no change point (HG), both the Mann–Kendall test and Şen's innovative trend analysis implied an increasing trend only in October precipitation.

The Black Sea's surface temperature is more sensitive to environmental changes due to its semi-enclosed structure (Miladinova et al. 2017). Unlike the findings of Miladinova et al. (2017), the surface temperature in the Black Sea (SST) show a remarkable increasing long-term trend during the last century (Ginzburg et al. 2004, Shapiro et al. 2010, Lebedev et al. 2017, Sakallı & Başusta 2018). For example, SST shows a 0.64°C increase in per decade in the 34 years between 1982–2015 in the Black Sea due to climate change (Sakallı & Başusta 2018). In Bartın offshore, the longitudinal and latitudinal means in mean daily SST show also an increasing trend from 1982 to 2015 (Sakallı & Başusta 2018).

Homogeneity testing is applied to ensure that time fluctuations in the climate data are only due to the factors related to weather and climate, and non-climatic changes due to station relocation or instrumentation changes need to be removed from the climate variables investigated (Aguilar et al. 2003). The Bartın Meteorological Station (BMS) has not been relocated, and its instruments and measurement methods have not changed in the period researched. Besides, in a lot of climate studies at the local and regional scale, BMS's data has been used (Göktürk et al. 2008, Dikbas et al. 2010, Sahin & Cigizoglu 2010, Iyigun et al. 2013, Türkeş & Erlat 2018). Moreover, most of the 68-time series belonging to the climate variables investigated in the present study are homogenous (70.5%). The climate variables studied have not been under artificial effects like station relocation and urbanization (urban heat island), therefore the remarkable increasing long-term trends in air temperatures over the 51 year period in Bartın might be attributed to climate change. During the 51 year period (1965–2015) in Bartın province, in air temperatures, the highest rate of change per decade is in August (0.55°C for T_{max}, 0.46°C for T_{min} and 0.43°C for T_{mean}) based on Sen's slope.

Under the conditions of global climate change, to strengthen our understanding of the impact of climate change on local geography, studies like the present work should be carried out on a local scale with different methodological approaches. Such local climate investigations are very important for adaptation studies at the local scale against possible climate change impacts on agriculture, forestry, health, natural hazards etc.

CONCLUSION

Due to the hazardous effects of global warming, studies on climate change/variability have been increasing at both the global, regional and local scales. It is thought that Bartın province in Turkey's western Black Sea coast will be relatively less affected by global climate change compared to the Mediterranean region. However, in the study, using four different homogeneity tests for change-point detection, the modified Mann–Kendall test and Şen's innovative trend method for trend analysis, and Sen's slope test for the magnitude estimation of trends have proven that there has been an increase in maximum, minimum and mean air temperatures in summer months since the 1990s (especially in August). However, we did not find any evidence of a decreasing or increasing trend for precipitation. Even so, based on the version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset (Harris et al. 2020), it is known that the vapour pressure in the grid where the Bartın Meteorology Station is located has been an increasing trend for the last 25 years. The humid air mass coming over the warming western Black Sea might increase the severity of the precipitation by rising and hitting the northern slopes of the mountains in Bartın province. Therefore, this province and its environs might be affected by a more humid and warmer climate than today. Since increasing temperatures and tree cover loss (*Global Forest Watch*, URL) might adversely affect the catchment area, river basin and water resources by breaking the natural balance during the global climate crisis, the future management plans of natural resources in Bartın province, especially related to agriculture, forest and water, need to take a 0.55°C rate of change per decade in terms of maximum temperature into account.

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