RESEARCH ARTICLE

Can innovative trend analysis identify trend change points?

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Abstract

Trends in temperature series are the main cause of climate change. Because solar energy directs hydro-meteorological events and increasing variations in this resource change the balance between events such as evaporation, wind, and rainfall. There are many methods for calculating trends in a time series such as Mann-Kendall, Sen's slope estimator, Spearman's rho, linear regression and the new Sen innovative trend analysis (ITA). In addition, Mann-Kendall's variant, the sequential Mann Kendall, has been developed to identify trend change points; however, it is sensitive to related data as specified by some researchers. Şen_ITA is a new trend detection method and does not require independent and normally distributed time series, but has never been used to detect trend change points. In the literature, multiple, half-time and multi-durations ITA methods are used to calculate partial trends in a time series without identifying trend change points. In this study, trend change points are detected using the Şen_ITA method and named ITA_TCP. This approach may allow researchers to identify trend change points in a time series. Diyarbakır (Turkey) is selected as a study area, and ITA_TCP has detected trends and trends change points in monthly average temperatures. Although ITA detects only a significant upward trend in August, given the 95% statistical significance level, ITA_TCP shows three upward trends in June, July and August, and a decreasing trend in September. Critical trend slope values are obtained using the bootstrap method, which does not require the normal distribution assumption.

Keywords: Climate change, trend, partial trend, trend change point, Şen innovative trend analysis.

1. Introduction

Climate change makes itself feel more and more with the increasing carbon level. In particular, it is assumed that climate change is effective in the last two or three decades. However, the measurement of hydro-meteorological data continues for several centuries. Trend detection methods such as Mann-Kendall, Şen slope estimator, linear regression, and Şen innovative trend analysis (ITA) consider that a time series has a trend or not as total (Mann 1945; Sen 1968; Kendall 1975; Şen 2012). In addition, this is current in simulation studies to test the strength of trend detection methods (Burn and Hag Elnur 2002a; Yue et al. 2002; Bayazit and Önöz 2007).

However, a time series may have a trend for its certain part, because the climate change phenomenon is new according to hydro-meteorological data measurement. In literature, sequential Mann-Kendall (MK_S) is used to detect trend change points by Sneyers, (1991). The author applied MK to sequential forward and reverse time series obtained from the main time series. If there is no significant trend, the author said that the test statistical curves from the MK overlay several times, otherwise the intersection of these curves gives the time of the beginning of the trend. This method is sensitive to correlated data and needs to some assumptions as normal distribution and long data length. Recently developed ITA method does not require an independent time series, normal distribution assumption, and long data length, and these restrictive assumptions may not always be in a time series. Many researchers have used this method because of these advantages as well as visual trend definition

(Burn and Hag Elnur 2002b; Sonali and Nagesh Kumar 2013; Dabanlı et al. 2016; Elouissi et al. 2016; Şen 2019; Wu and Qian 2017; Deng et al. 2017; Şen 2017; Ahmad et al. 2018; Alashan 2018; Caloiero et al. 2018; Li et al. 2018; Morbidelli et al. 2018; Zeybekoğlu and Karahan 2018; Wu et al. 2019; Wang et al. 2020). On the other hand, the researchers have never used this method to detect trend change points in the sequential version in a time series, but they have used it to detect partial trends.

Mohorji et al., (2017) examined monthly global temperature trends using the ITA method. The monthly temperature series are used as two-half and multi-duration to detect partial trends. Tabari et al., (2017) used ITA with a quantile perturbation approach to detect partial trends in decadal monthly and annual flows in Qazvin plain in Iran. They concluded that there are positive anomalies in the 1990s and negative anomalies in the 2000s. Öztopal and Şen, (2017) explored the possible partial trends in rainfall records in 35 stations in Turkey. In the study, the precipitation records are divided into three sub-periods, and the first period is compared to the other two sub-periods using ITA to detect partial trends. Güçlü, (2018a) divided a time series into two equal sub-series and obtained different trends in these time series as increasing-increasing, increasing-decreasing, decreasing-increasing, decreasing-decreasing. Furthermore, Güçlü (2018b) considered a time series data length as 6t and checked against its first 4t with last 4t, ie the dual innovative trend analysis (D-ITA) and its first 3t with middle 3t and last 3t, ie the triple innovative trend analysis (T-ITA). Although ITA is used to detect partial trends in a time series, trend change points are not detected in these studies.

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Received 14 Jan 2020 Revised 17 Jan 2020 Accepted 17 Jan 2020
Brilliant Engineering 3 (2020) 6-15
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<https://doi.org/10.36937/ben.2020.003.002>

In this study, trend change points are calculated by the ITA method (ITA_TCP) with sequential trend slope values for the forward and backward direction of a time series. Also, the ITA method is applied to the time series. The results obtained from the ITA method and ITA_TCP approach are compared with each other. The ITA_TCP approach enables researchers to detect the start time of the trend. Moreover, this approach may be an answer to the basic question of where (from which point) the main time series should be divided sub-series.

2. Methodology

ITA is a new trend detection method with a high visual capability and stable results, even if there is an autocorrelation effect in the given time series. The method compares substantially a parent time series as two sub-series. The division of the parental time series from the midpoint into two sub-series or series of equal lengths allows researchers to use all data. However, climate change is a new problem according to hydro-meteorological data measurement and a trend obtained from all data duration may be smaller than the current situation or ignored. For this purpose, it is important to detect trend change points in climate change studies.

Assume that Z is a hydro-meteorological time series with components $Z_1, Z_2, \dots, Z_n$. If the parent time series, Z , is divided into two sub-series from the midpoint, the first half, X , and the second half, Y , sub-series are obtained. The first (second) half-series is plotted on the horizontal (vertical) axis on a graph. Thus, scatter points are seen on the graph and a 1:1 (45°) line is drawn on the same graph. If all scatter points are above (below) the 1:1 line then there is a monotonic increasing (decreasing) trend. There is no trend if the scatter points are over the 1:1 line. In another case, if the scatter points are under the 1:1 line at minimum (maximum) values and above the same line at maximum (minimum) values, there is a non-monotonic increasing (decreasing) trend. These comments allow researchers to visually determine a local trend in any time series, even for low, medium and high data ranges.

ITA calculates trends as in Eq.1; $\bar{Y}$, $\bar{X}$, and n is first and second sub-series averages and data length. This approach enables us to use all data and calculate the mean trend in parent time series. In order to detect trend change points in the time series, successive s values such as $s_1, s_2, s_3, \dots, s_k$ can be calculated as seen in Eq.2 for forwarding time series. Here, s_k and Z represent sequential trend slope (s) values and the main time series. If (Z') is assumed as the backward series of the series then trend slopes of backward series (s'_k) can be calculated as seen Eq.3.

$$S = \frac{2(\bar{Y} - \bar{X})}{n} \quad (1)$$

$$S_1 = \frac{Z_2 - Z_1}{2/2}$$

$$s_2 = \frac{\frac{1}{2}(Z_3 + Z_4) - \frac{1}{2}(Z_1 + Z_2)}{4/2}$$

$$s_3 = \frac{\frac{1}{3}(Z_4 + Z_5 + Z_6) - \frac{1}{3}(Z_1 + Z_2 + Z_3)}{6/2}$$

in general form

$$S_k = \frac{\sum_{i=k+1}^{2k} Z_i - \sum_{i=1}^k Z_i}{k^2} \quad (2)$$

$$S'_k = \frac{\sum_{i=k+1}^{2k} Z'_i - \sum_{i=1}^k Z'_i}{k^2} \quad (3)$$

The calculated trend values may sometimes not be statistically significant. The bootstrap method employed to calculate critical trend slopes is used in this study. The method is based on generating random series using observed time series values. In this study, 1000 random time series with data length observed using the bootstrap method are produced. Trend slopes from 1000 random series are calculated and sorted in ascending order. The fiftieth (decreasing) and nine hundred fiftieths (increasing) trend slope values represent critical trend slopes considering a 95% statistical significance level. A triggered dimensionless parameter, zz , is as seen in Eq.4. Here s and s_{cri} are the trend slope and critical trend slope values. If the zz parameter is equal to or greater than 1 (-1), there is an increasing (decreasing) trend.

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}} \sigma \sqrt{1 - \rho_{yx}} \quad (4)$$

$$s_{cri} = 0 \pm 1.96\sigma_s \quad (5)$$

Simulation experiments are used to visualize sequential trend slope values to detect trend change points. The series with one hundred data length is generated by the computer program and trend slope values $s = \pm 0.05$ are added to the first and/or second half of these series to obtain various series with different partial trends.

Firstly, a 0.05 (-0.05) trend slope is added to the first (second) fifty values of the random series to obtain increasing-decreasing time series (Figure 1_a1). The trend slope curves for forward and backward temperature series are obtained using Eqs. 2 and 3. In Figure 1_a2, the trend slope curves of the forward and reverse series intersect with the approximate fiftieth value on the horizontal axis. This point indicates a trend change point.

Figure 1. Partial trend possibilities a) increasing-decreasing time series and s values b) decreasing-increasing time series and s values c) increasing-increasing time series and s values d) decreasing-decreasing time series and s values e) trendless time series and s values

Secondly, -0.05 (0.05) trend slope (s) is added to the first (second) half of the random series to obtain a decreasing-increasing time series (Figure 1_b1). These curves intersect with the fiftieth value again (Figure 1_b2).

Thirdly, increasing-increasing time series is obtained adding trend slope values 0.05 (0.10) to first (second) half of the random series (Figure 1_c1). However, the s curves move to parallel each other and there is a maximum vertical distance in the fiftieth value in Figure 1_c2.

Fourthly, decreasing-decreasing time series with trend slope values -0.05 (-0.10) for first (second) half of the random series is

seen in Figure 1_d1. Again, the maximum vertical distance among forwarding and reverse series s curves is in the fiftieth value (Figure 1_d2). The trend curve of the forward series is above (below) the trend curve of the reverse series in increasing-increasing (decreasing - decreasing) time series (Figure 1_c2 and d2).

Lastly, trendless time series generated random values are seen in Figure 1_e1. The trend curves of the forward and reverse time series intersect several times as indicated by Sneeeyr (Figure 1_e2).

3. Study Area and Application

Sequential trend slope values of monthly temperatures series belong to Diyarbakır, Turkey, are analyzed through Şen innovative trend analysis (ITA) to detect trend change points. The province of Diyarbakır is located at the upper Tigris River (average annual flow of 490 m³/s (Şen 2018)(Figure 2a and 2b). The city with 37.9 N and 40.2 E coordinates has been an important center since the Hellenistic period, through the Roman, Sassanid, Byzantine, Islamic and Ottoman times to the present (UNESCO). The ancient city of Diyarbakır is bounded with 5.8 km long and turbot shaped city walls, which include numerous towers and gates (Figure 2c). The city surrounded by walls has fertile agricultural lands, the Tigris River and the abundant sunlight. The mean annual temperature value of the city is 15.6 °C and monthly temperatures

observed from 1978 to 2008 range from 1.35 °C (January) to 31.16 °C (July) (Table 1). The minimum temperatures have negative values only in the winter season (December, January, and February). The mean and median temperatures are positive in all months and highest in July. The autumn season (September, October, and November) has minimum absolute skew coefficients and the standard deviation values are highest in winter. According to ITA, there are visually decreasing trends in February, April, May, September and December; and increasing trends in June, July, August, and October (Figure 3). In addition, there is no visually monotonic trend in January, March and November months. Although there are visually increasing and decreasing trends, trend slope in August is only statistically significant at the 95% significance level (Table 2).

Figure 2. The map of the study area a) Turkey b) Recently Diyarbakır city c) Ancient Diyarbakır city

Figure 3. Monthly average temperature trends between the years 1971-2008 in Diyarbakır (* the dashed (continuous) line indicates the trend line (1:1 no trend)).

Table 1. Statistical information about of Diyarbakır city average monthly temperatures.

	Months (Observed years from 1978 to 2008)											
	1	2	3	4	5	6	7	8	9	10	11	12
Minimum (°C)	-5.49	-3.24	4.45	10.31	16.31	23.44	28.29	28.03	22.40	13.95	6.02	-0.65
Mean (°C)	1.35	3.29	8.44	13.74	19.25	26.26	31.16	30.24	24.69	17.10	8.87	3.58
Median (°C)	1.89	3.09	8.94	13.52	19.44	26.41	31.34	30.19	24.76	16.97	8.88	3.65
Maximum (°C)	4.71	8.37	11.59	17.89	21.49	28.48	33.45	32.65	26.70	20.57	12.50	7.33
Standard deviation (°C)	2.71	2.53	1.76	1.49	1.49	1.11	1.04	0.98	0.96	1.30	1.57	1.88
Skew	-0.93	-0.44	-0.70	0.58	-0.34	-0.41	-0.71	0.25	0.13	0.16	0.17	-0.37

Table 2. ITA trend parameters for Diyarbakır monthly temperatures between 1971 and 2008.

Months	First half mean	Second half mean	Standard deviation (σ)	Correlation (ρ)	Significance level (α)	Critical slope (s_{cri})	Trend slope (s)	Result
January	1.43	1.48	2.69	0.71	0.05	0.075	0.010	No trend
February	3.64	2.94	2.57	0.88	0.05	-0.078	-0.037	No trend
March	8.52	8.36	1.79	0.94	0.05	-0.047	-0.008	No trend
April	14.05	13.43	1.51	0.75	0.05	-0.040	-0.033	No trend
May	19.47	19.03	1.51	0.91	0.05	-0.041	-0.023	No trend
June	26.07	26.45	1.13	0.85	0.05	0.030	0.020	No trend
July	30.98	31.35	1.06	0.90	0.05	0.029	0.019	No trend
August	29.90	30.57	1.00	0.96	0.05	0.028	0.035	Increasing trend
September	24.94	24.44	0.97	0.77	0.05	0.028	-0.026	No trend
October	16.95	17.26	1.32	0.85	0.05	0.037	0.016	No trend
November	8.97	8.78	1.59	0.85	0.05	-0.043	-0.010	No trend
December	3.84	3.32	1.91	0.76	0.05	-0.055	-0.028	No trend

Sequential trend slope values are calculated by ITA_TCP for the forward and backward series of monthly mean temperatures in Diyarbakır using Eqs 2, 3 and 4 (Figure 4). The forward and backward trend curves intersect several times in January, February, March, April, May, October, November, and December, as shown in Figure 1_e2. It can be said that there is no trend in these months. In June, July and August, there are decreasing-increasing trends as in Figure 1_b2. In addition, there is an increasing-

decreasing trend in September as seen in Figure 1_a2 template. Trend change points are detected as the intersection point of trend slope curves of forwarding and reverse series. The trend change points for June, July, and August are detected as 1993 years as seen in Figure 4. In September month, there is a transition region for a trend change and trend change point is selected as the 1987 year because there is a maximum vertical distance among trend slope curves in the year.

Figure 4. ITA_TCP trend curves of forwarding and backward temperature series for Diyarbakır monthly mean temperatures.

Sequential trend slope values are calculated by ITA_TCP for the forward and backward series of monthly mean temperatures in Diyarbakır using Eqs 2, 3 and 4 (Figure 4). The forward and backward trend curves intersect several times in January, February, March, April, May, October, November, and December, as shown in Figure 1_e2. It can be said that there is no trend in these

months. In June, July and August, there are decreasing-increasing trends as in Figure 1_b2. In addition, there is an increasing-decreasing trend in September as seen in Figure 1_a2 template. Trend change points are detected as the intersection point of trend slope curves of forwarding and reverse series. The trend change points for June, July, and August are detected as 1993 years as

seen in Figure 4. In September month, there is a transition region for a trend change and trend change point is selected as the 1987

year because there is a maximum vertical distance among trend slope curves in the year.

Figure 5. ITA_TCP trend slopes for Diyarbakır monthly mean temperature series.

Table 3. ITA trend parameters for Diyarbakır monthly temperatures between 1971 and 2008.

Months	First half mean	Second half mean	Standard deviation (σ)	Correlation (ρ)	Significance level (α)	Critical slope (s_{cri})	Trend slope (s)	Result
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June	26.07	26.45	1.13	0.85	0.05	0.030	0.020	No trend
July	30.98	31.35	1.06	0.90	0.05	0.029	0.019	No trend
August	29.90	30.57	1.00	0.96	0.05	0.028	0.035	Increasing trend
September	24.94	24.44	0.97	0.77	0.05	0.028	-0.026	No trend
October	16.95	17.26	1.32	0.85	0.05	0.037	0.016	No trend
November	8.97	8.78	1.59	0.85	0.05	-0.043	-0.010	No trend
December	3.84	3.32	1.91	0.76	0.05	-0.055	-0.028	No trend

4. Results and Conclusions

ITA method and ITA_TCP approach are employed for the mean temperature monthly series for Diyarbakır. The bootstrap technique, which does not need the normal distribution assumption, calculates the critical trend slopes. ITA method gives only an increasing trend in August month according to the 95% statistical significance level although ITA_TCP gives three increasing (June, July, and August) and one decreasing trend (September). Because the ITA method divides a parent time series at the midpoint as two half series and this point may not be trend change point. Since the ITA method could not determine trend change points, it could not reveal the trends in June, July, and September. Trend change points are detected by the ITA_TCP method. The method found three increasing trends for June, July and August months and a decreasing trend for September month regarding 95% statistical significance level. The trend change point is 1993 year for June, July, and August months and 1987 year for September. Although some researchers to determine partial trends in a time series use the ITA method, trend change points are detected for the first time in this study. In addition, ITA_TCP gives bigger trend slope value ($s=0.053$) according to ITA in August ($s=0.035$). This shows that climate change has a greater impact on hydro-meteorological events than has been recently calculated by ITA. This approach is particularly useful for analyzing hydro-meteorological events according to changing climate scenarios. Also, this approach (ITA_TCP) can be used easily other time series.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest.

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