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Investigation of Konya Meteorological Snow Cover Depth Trend Using MK and ITA

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ABSTRACT
This study investigates the snow cover depths trend in Konya province according to different approaches. For this purpose, trend analysis was carried out using the annual maximum snow cover depths data of 5 different stations in Konya. Trend data analysis at the stations was performed according to the Mann-Kendall and Innovative Sen Methods. In addition, the slope of the trend was found with Sen's Slope Estimator Test. According to the Mann-Kendall method, an increasing trend was observed in the annual maximum snow cover depth recorded in Beyşehir, but no trend was observed in other stations. According to the innovative Sen method, an increasing trend was observed in Konya Airport, Beyşehir, and Cihanbeyli stations, and a decreasing trend was observed in Akşehir and Ereğli. Trends obtained with different approaches reveal that the available TS EN 1991-1-3 standard, which determines snow loads, needs to be re-evaluated for Konya Airport, Beyşehir, and Cihanbeyli.

Konya Meteorolojik Kar Örtüsü Derinlik Yöneliminin MK ve ITA Yöntemleri Kullanılarak Araştırılması

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ÖZ
Bu çalışmada Konya ilindeki kar örtüsü derinliği yönelimi farklı yaklaşımlara göre araştırılmıştır. Bu amaçla Konya'daki 5 farklı istasyonun yıllık maksimum kar örtüsü derinliği verileri kullanılarak yönelim analizi yapılmıştır. İstasyonlardaki eğilim verisi analizi Mann-Kendall ve Inovative Trend Analizi'ne göre yapılmıştır. Ayrıca eğilimin eğimi Sen'in Eğim Tahmin Testi ile bulunmuştur. Mann-Kendall yöntemine göre Beyşehir'de kaydedilen yıllık maksimum kar örtüsü derinliğinde artış eğilimi gözlenirken, diğer istasyonlarda eğilim gözlenmemiştir. Inovative Trend Analizi'ne göre Konya Havalimanı, Beyşehir ve Cihanbeyli istasyonlarında artış eğilimi, Akşehir ve Ereğli'de azalış eğilimi gözlenmiştir. Farklı yaklaşımlarla elde edilen eğilimler, kar yüklerini belirleyen mevcut TS EN 1991-1-3 standardının Konya Havalimanı, Beyşehir ve Cihanbeyli için yeniden değerlendirilmesi gerektiğini ortaya koymaktadır.

1. INTRODUCTION

In addition to dynamic and other static loads, snow loads also significantly impact the design of steel structures. Building collapses due to unexpected snow loads cause financial losses and threaten human life. As far as followed by the media, such situations are often encountered in our country [1]. However, in Turkey, insufficient statistical information on roof collapses and damages caused by snow accumulation prevents a precise evaluation of the issue. One of the main reasons for roof collapses in buildings is the excessive snow load accumulated on the roof, which is higher than the expectation of the design code. The characteristics of meteorological events in recent years have become a matter of concern for the design of steel structures.

Climate change is experienced in the world due to many factors. Climate change is defined as changes in the average state of the climate over a long period caused by different variables [2-4]. It is vital to know the change in meteorological data over time to reveal the possible consequences of the effects of snowfall on steel structures due to climate change. Changes in meteorological data over the years are determined using methods such as trend analysis with the help of statistical approaches. The trend means an increase or decrease in the values of a time-dependent random series over time [5-6]. Determining the existence of a trend in a time-dependent random series allows us to obtain information about how that series behaves from past to present. Based on the knowledge of the behavior of the series, predictions can be made about the possible future behavior of the variable in the series [7-9]. As a result of trend studies, future increases or decreases in snowfall can be predicted, and various precautions can be taken, or plans can be made to minimize the adverse effects of the possible situation.

One of the main reasons for collapses in roofs is that the snow load values taken into account in the design of steel buildings are smaller than the actual snow loads that occur during snowfall and thus accumulate on the building roof [10]. Especially considering the collapses that occurred in Türkiye in the past years due to very heavy snowfall, it is very important to reconsider and update snow loads to ensure that buildings can resist heavy snowfall [11].Turkey has different climate types in its geography. For this reason, the snow loads to be used in building designs must be considered according to the current climate conditions of the location where the building will be built. If we want to ensure the safety of buildings in Türkiye, we must update the snow loads in the standards according to the current climate conditions.

Some researchers have presented studies revealing the deficiencies of the standards valid in Türkiye for snow load [1,12,13]. Durmaz and Daloğlu [1] made statistical analyses of snow cover depths obtained from nearly 100 stations in Türkiye. They converted the snow cover depth to snow-water equivalent. Using appropriate distributions, they obtained the ground snow load values for the last 50 years and compared them with those recommended in Turkish codes. Aladağ [12] revealed the deficiencies of the available codes for snow load by creating current snow load calculation values and maps with the help of appropriate probability distributions using the data obtained from the General Directorate of Meteorological Affairs. Türkeş et al. [4] investigated the observed changes in rainfall intensity and anomalies with the data obtained from 111 stations in their study. They used the Mann-Kendall (MK) and Innovative Trend Analysis (ITA) to examine the rainfall trend at the designated observation stations. Baltaci et al. [13] conducted a climatological analysis using daily new snow cover data from 93 meteorological stations over Turkey. Baltaci et al. [14] made a climatic analysis of snowfall events for winter periods in Istanbul. For this purpose, they first obtained the daily snow cover depths for 1971-2006 and then investigated the role of snowfall events under the influence of the Black Sea in the formation of snow bands.

Although snow cover depth has many adverse effects on our social and economic life, there are a limited number of snowfall studies for our country. In contrast, most studies focus on satellite snow cover data [13]. Despite the increasing literature on precipitation trends, drought, and satellite snow cover analyses due to climate change, the number of studies representing the snow cover depth trends of certain parts of our country is insufficient.

This study uses different approaches to determine the annual maximum snow cover depth trends in Konya city center and its four districts.

2. MATERIAL AND METHOD

2.1. Study Area and Data

Our study area, the Konya Closed Basin, has limited water resources and large agricultural lands. Konya has a continental climate. Summers are dry and hot; winters are cold and snowy. The temperature difference between day and night is between 16-22 degrees in summer. In spring and winter, due to humidity, this difference drops to 9-12 °C. Snow stays on the ground for an average of 3 months. Konya is greatly affected by the hot-cold air centers around it. Although it is located in the southernmost part of Central Anatolia, it is colder than other Central Anatolian cities. This is because the central Taurus Mountains completely block the effect of the sea [14].

As the scope of this study, five stations in Konya, established by the General Directorate of Meteorology Affairs, were considered. The stations are in Konya Airport, Akşehir, Beyşehir, Cihanbeyli, and Ereğli districts. They are numbered 17244, 17239, 17242, 17191, and 17248, respectively. Numerical information of the stations is given in Table 1, and their geographical locations are given in Figure 1. The data shows annual maximum snow cover depths.

Table 1. Location of the stations

Location	Station no	Altitude	Coordinate information
Konya Airport	17244	1016	37°59'01.3"N 32°34'26.4"E
Akşehir	17239	1025	38°22'07.7"N 31°25'46.9"E
Beyşehir	17242	1131	37°40'39.7"N 31°44'46.7"E
Cihanbeyli	17191	955	38°39'02.1"N 32°55'18.7"E
Ereğli	17248	1055	37°31'31.8"N 34°02'54.6"E

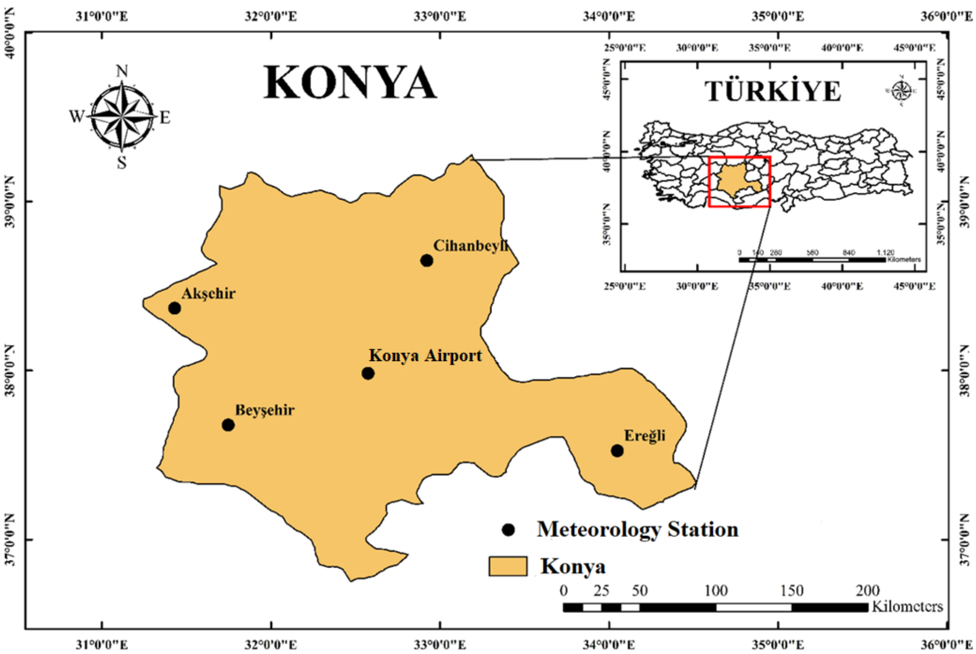

Figure 1. Map locations of stations

Figure 2-6 shows the distribution of meteorological data of Konya Airport, Akşehir, Beyşehir, Cihanbeyli, and Ereğli stations over time and their 5-year average values, respectively. Annual maximum snow cover depth data for the stations examined within the scope of the study were obtained from the General Directorate of Meteorology Affairs. The beginning of the time series for Konya airport is 1922. It is 1941 for Akşehir, 1931 for Beyşehir, and 1964 for Cihanbeyli and Ereğli. The data in the time series continues until 2023.

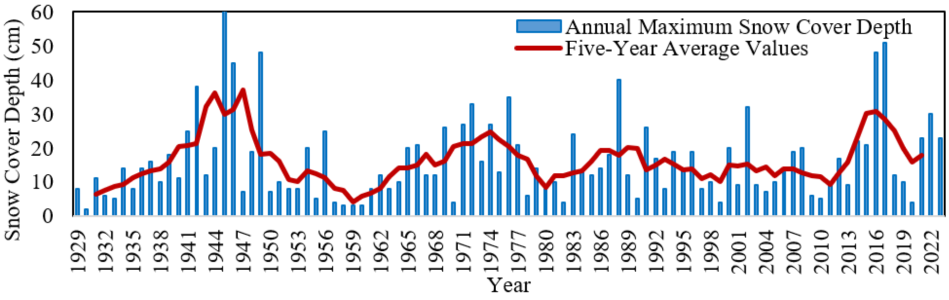

Figure 2. Time series of meteorological data of Konya Airport station

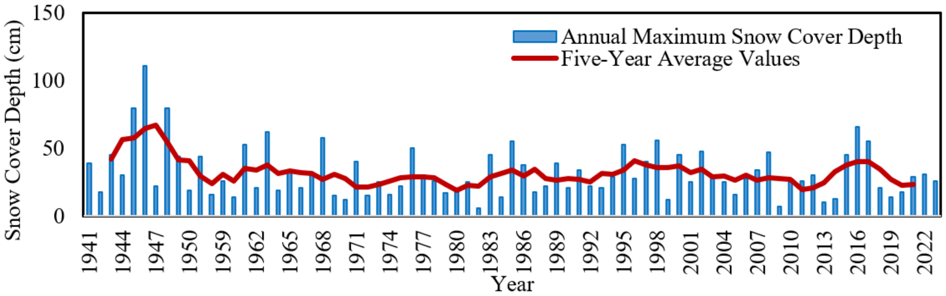

Figure 3. Time series of meteorological data of Akşehir station

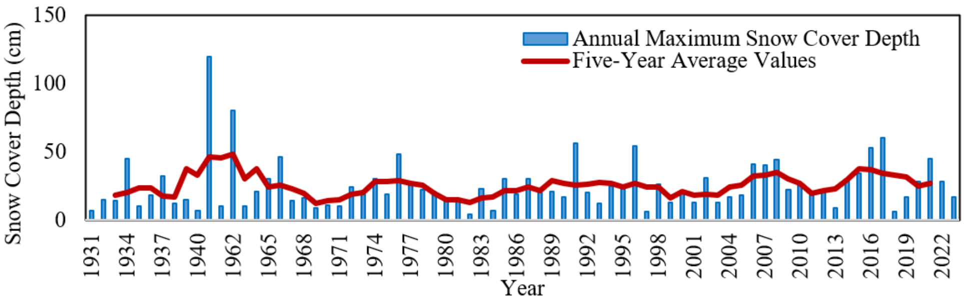

Figure 4. Time series of meteorological data of Beyşehir station

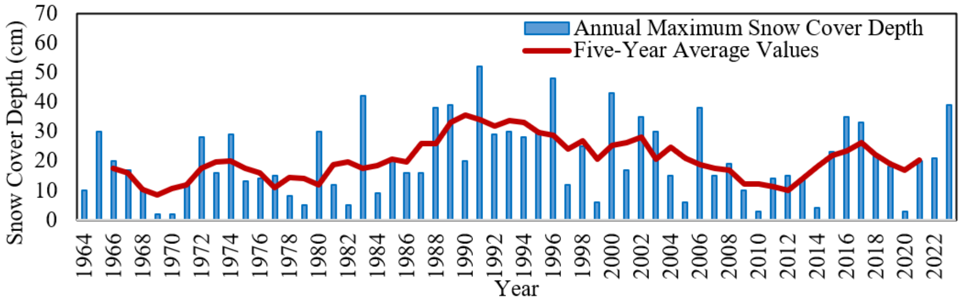

Figure 5. Time series of meteorological data of Cihanbeyli station

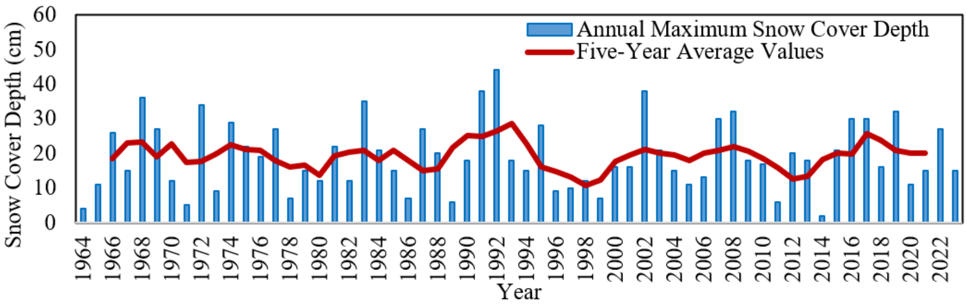

Figure 6. Time series of meteorological data of Ereğli station

It is observed from Figure 2-6 that the highest snow cover depth at Konya airport reached 65 cm in 1945. The highest snow cover depth reached 111 cm in Akşehir in 1946, 120 cm in Beyşehir in 1960, 52 cm in Cihanbeyli in 1991, and 44 cm in 1992 in Ereğli.

2.2. Mann-Kendall Trend Test

The Mann-Kendall Trend Test (MK) is one of the methods of testing the trend when considering a time series. This non-parametric method was developed by Mann [16] and Kendall [17]. The MK test statistic is calculated as follows:

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

$$sgn(x_j - x_k) = \begin{cases} 1 & (x_j - x_k) › 0 \\ 0 & (x_j - x_k) = 0 \\ -1 & (x_j - x_k) ‹ 0 \end{cases} \tag{2}$$

Positive *S* values indicate an expanding (increasing) trend and a negative *S* value reveals a decreasing trend in the data time series. Here, n is the length of the dataset, x_j and x_k are the successive information esteems on occasion j and i, and sgn(xj-xk) means the sign capacity that takes on the values 1, 0, or−1. Variance of S with normal distribution and zero mean is calculated by:

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

The equation below is obtained for tests $n > 10$:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_i^r t_i(t_i - 1)(2t_i + 5)}{18} \tag{4}$$

The standardized test statistic *Z* value, which determines whether the Mann-Kendall test is significant or not, is calculated by utilizing the following equations:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \tag{5}$$

The Mann-Kendall test determines the significance by comparing *Z* with the critical *Z* value. Depending on which α significance level the study is examined, if the $|z| \leq z_\alpha$ condition is valid, it is accepted that there is a trend. If there is a trend, it is concluded that there is an increasing trend if the *Z* sign is (+) and a decreasing trend if it is (-). Since this method does not have to comply with any distribution, it appears useful among researchers [18]. Many researchers have used this approach for their trend studies [19-22] because of this.

2.3. Innovative Trend Analysis

The Innovative Trend Analysis (ITA), developed by Sen [23], is a method that presents the data obtained as a result of the analysis in linear graphic form. The approach differs from other non-parametric trend analysis methods. It gives results even if the data do not follow a normal distribution, the data is small, and there is internal dependence on the data [23].

In this approach, the data time series is divided into two equivalent parts, and each sub-series is organized in ascending order independently. The sub-arrangement's first half (x_i) is put on the x axis, and the second half (x_j) is set on the y axis of a Cartesian coordinate system.

1:1 line is drawn on the graph. There is no trend if the data points in a scatter plot are collected in a straight line 1:1. If the data points accumulate in the triangular area below the 1:1 straight line, the time series shows decreasing trends. If above, it means that the time series shows increasing trend [23]. Another advantage that distinguishes this method from other non-parametric methods is that it allows time series to be divided into three categories: “low”, “medium” and “high” (Figure 7).

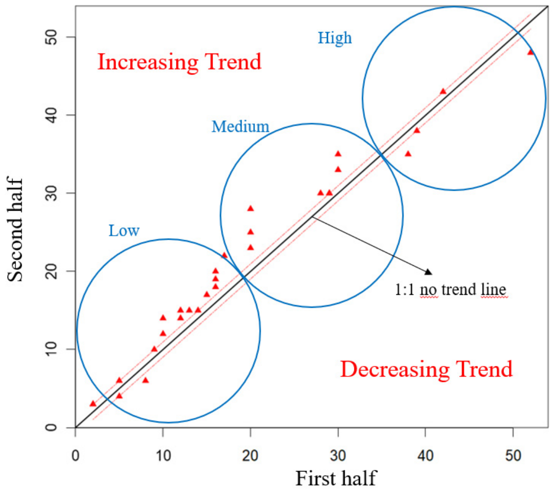

Figure 7. Graphical representation of the ITA

Sen [24] proposed Equation 6. to determine ITA's slope (*S*). The slope determined by the equation also shows the magnitude of the trend.

$$S = \frac{2(\bar{x} - \bar{y})}{n} \tag{6}$$

The standard deviation of the trend slope and confidence limit (CL) of the trend are calculated in equations 7 and 8, respectively.

$$\sigma_S = \frac{2\sqrt{2}}{n\sqrt{n}} \sigma \sqrt{1 - \rho_{\overline{xy}}} \tag{7}$$

$$CL_{(n-1)} = 0 \pm S_{kr}\sigma_S \tag{8}$$

Here, n is the length of the dataset, x is the average of the first half-time series, and y is the average for the second half. $\rho_{\overline{xy}}$ in Equation (7) refers to the cross-correlation coefficient between the first and second half of the series, and σ_s is the standard deviation of the slope. Equation (8) was created to determine the upper confidence and lower confidence limit values, which are the confidence limits. The term S_{kr} in this equation refers to the critical *Z* value at the relevant confidence level. If the slope value *S* of each station is outside the lower and upper confidence limits, it indicates a trend in the time series. A positive *S* value indicates an increasing trend, while a negative value indicates a decreasing trend [24].

2.4. Sen's Slope Test

Sen [25] presented a non-parametric method to estimate the magnitude of trends in the data time series. In this method, the slope of “n” pairs of data ((T_i) i = 1, 2, … n) can be estimated by using the following equation:

$$T = \frac{x_j - x_k}{j - k} \tag{9}$$

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & n\ (odd) \\ \frac{1}{2}\left(T_{\frac{x}{2}} + T_{\frac{N+2}{2}}\right) & n\ (even) \end{cases} \tag{10}$$

3. RESULTS AND DISCUSSION

Within the scope of the study, annual maximum snow cover depths taken from 5 different stations in Konya province were considered, and trend analyses were performed using the MK and ITA. The slope was estimated with the help of Sen's Slope Estimator Test.

The MK test was used to evaluate trend analysis at a 0.05 significance level (95% confidence limit). If the absolute value of the standardized Z statistic obtained from the trend analysis was greater than 1.96, the trend was considered statistically significant. If the absolute value of Z was less than 1.96, it was concluded that there was no statistically significant trend.

MK trend analysis results of the annual maximum snow cover depth series at the stations are given in Table 2.

Table 2. Mann-Kendall test results

Stations	S	σ_s	Z	Trend state (a=%5)
Konya Airport	403	93425.67	1.315	None
Akşehir	-158	49620.00	-0.705	None
Beyşehir	471	44015.67	2.240	Statistically significant increasing trend
Cihanbeyli	134	134.00	0.871	None
Ereğli	79	79.00	0.511	None

According to the MK test, a statistically significant increasing trend was detected at the Beyşehir station at the 5% significance level ($Z = 2.240$, $p < 0.05$). Although the trend is upward in the data of Konya Airport, Beyşehir, Cihanbeyli and Ereğli, there is no trend in statistical significance. In the Akşehir data, the trend is decreasing and again no statistically significant trend is observed.

Within the scope of the study, Sen's innovative method was also used to investigate trends. In ITA, the slope value S of each station is compared with the lower and upper confidence limits. If the S value is outside the confidence limits, it is concluded that there is a trend in the time series. Trend analysis results obtained with ITA are given in Table 3. As a result of the ITA test conducted for the data of Konya Airport, Beyşehir, and Cihanbeyli stations, s values were calculated as 0.0095, 0.0753, and 0.0608, respectively. Comparing these slope values with the lower and upper confidence limits resulted in the conclusion that there is an increasing trend, considering that the s values are outside the limits and the s values are positive. s values for Akşehir and Ereğli were calculated as -0.0609, -0.0561, and it was concluded that there was a decreasing trend. Graphical results of the ITA are shown in Figure 8.

Table 3. Innovative trend analysis results based on confidence limit at 95%

Stations	Slope(s)	Indicator	Standart deviation	Correlation	Lower limit	Upper limit	Trend state
Konya Airport	0.0095	0.2807	0.0043	0.9869	-0.0083	0.0083	Increase
Akşehir	-0.0609	-0.6962	0.0178	0.9502	-0.0348	0.0348	Decrease
Beyşehir	0.0753	1.1620	0.0302	0.8701	-0.0592	0.0593	Increase
Cihanbeyli	0.0608	0.9302	0.0108	0.9801	-0.0211	0.0211	Increase
Ereğli	-0.0561	-0.8348	0.0099	0.9741	-0.0194	0.0194	Decrease

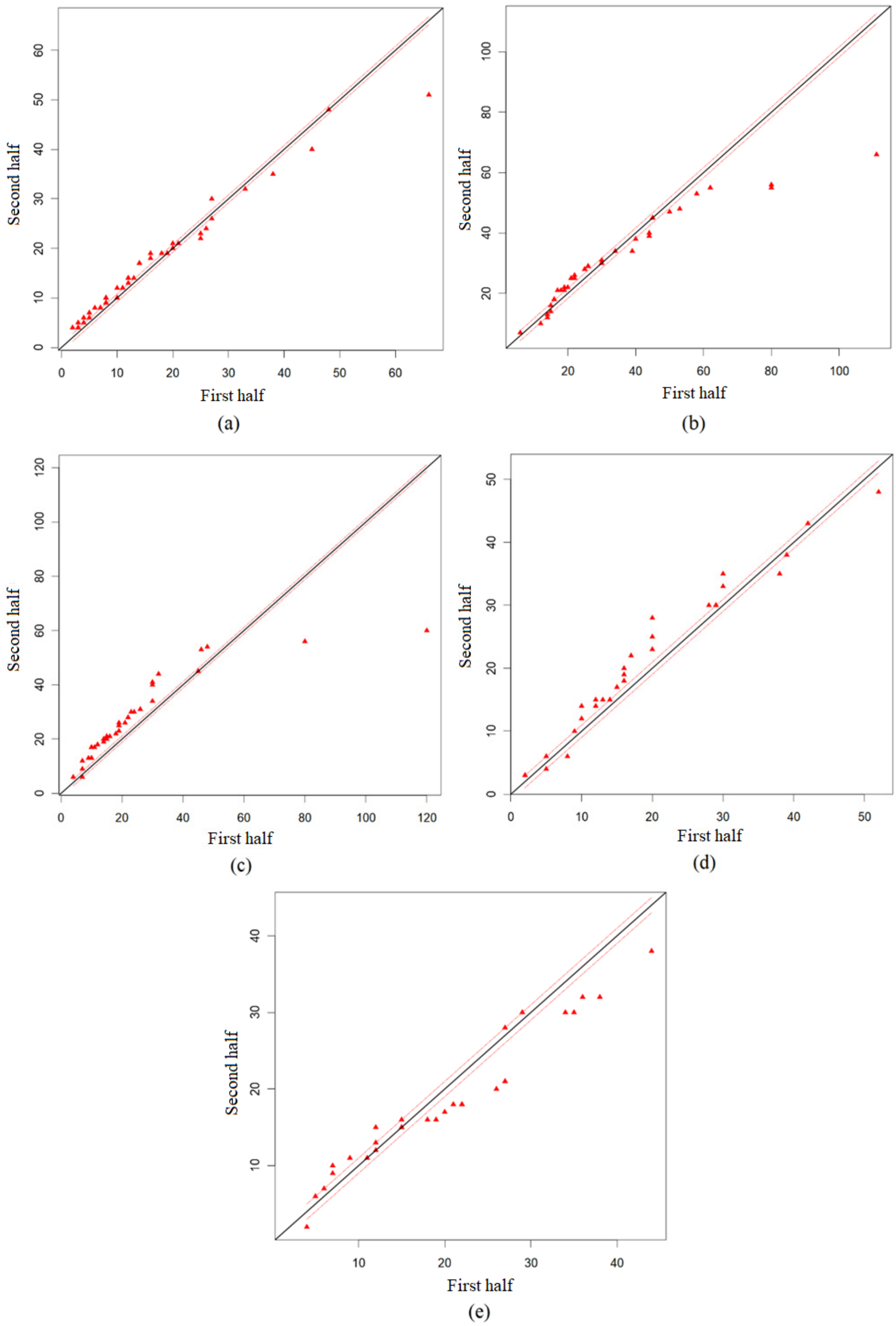

Figure 8. Trend graphs for snow cover depths obtained by the ITA (a) Konya Airport, (b) Akşehir, (c) Beyşehir, (d) Cihanbeyli, (e) Ereğli

Detailed information about the trends can be obtained by examining the graphs in Figure 8. In the ITA chart of Konya Airport station (Figure 8.a), it is understood that the data is mainly located in the upper triangle but in the lower area. This shows that the trend is increasing but at a low level. According to the chart given for Akşehir station (Figure 8.b), however, some of the data is located in the lower area of the upper triangle; most of the data is in the middle and the higher area of the lower triangle. Therefore, it is concluded that the trend is decreasing. When the graph obtained for Beyşehir (Figure 8.c) is examined, most of the data is located in the lower area of the upper triangle. Thus, it is concluded that the trend is increasing. At Cihanbeyli station (Figure 8.d), almost all of the data is in the upper triangle, scattered in the lower and middle areas. This shows that the trend is increasing. At Ereğli station (Figure 8.e), while the majority of the data is in the lower triangle, it is seen that the data in the lower triangle is in the middle and higher area. According to ITA, a decreasing trend was determined at this station.

A comparison of the results of trend analysis using MK and ITA for the stations within the scope of the study is given in Table 4. The trend analysis conducted for Beyşehir station revealed that the trend was increasing in both methods. While no trend was observed for the other four stations according to MK, an increasing trend is seen in some stations and a decreasing trend in others, according to ITA.

Table 4. Comparison of trend tests

Stations	Man-Kendall test	Inovative Sen test
Konya Airport	None	Increase
Akşehir	None	Decrease
Beyşehir	Statistically significant increasing trend	Increase
Cihanbeyli	None	Increase
Ereğli	None	Decrease

Sen's Slope Estimator test was also performed on the stations' annual snow cover data evaluated within the study's scope (Table 5.). The test results were obtained as 0.0395, -0.0556, 0.1508, 0.0667, and 0.0303 at Konya airport, Akşehir, Beyşehir, Cihanbeyli, and Ereğli stations. As a result of Sen's slope estimator test, it shows that the trend is increasing as the slope values are positive in Konya airport, Beyşehir, Cihanbeyli, and Ereğli. In Akşehir, the slope value is negative, with a decreasing trend.

Table 5. Sen’s slope estimator test results

Stations	Sen’s slope estimator test
Konya Airport	0.0395
Akşehir	-0.0556
Beyşehir	0.1508
Cihanbeyli	0.0667
Ereğli	0.0303

4. CONCLUSION

The study discusses the annual maximum snow cover depths of Konya Airport, Akşehir, Beyşehir, Cihanbeyli, and Ereğli stations in Konya Province. Mann-Kendall, Innovative Trend Analysis and Sen's Slope estimator test were conducted on these data, and the obtained trend analysis results were compared.

- According to ITA, an increasing trend was determined at Konya Airport station, while no trend was found as a result of MK.
- According to ITA, a decreasing trend was determined at Akşehir station, while no trend was found due to MK.
- An increasing trend was determined at Beyşehir station according to both MK and ITA methods.
- According to ITA, an increasing trend was determined at Cihanbeyli station, while no trend was found due to MK.
- According to ITA, a decreasing trend was determined at Ereğli station, while no trend was found due to MK.
- According to Sen's slope test, it is seen that the slope values in Konya airport, Beyşehir, Cihanbeyli and Ereğli are positive and the trend is increasing, while in Akşehir the slope value is negative and the trend is decreasing.

As a result of all these studies, an increasing trend emerged in both methods at Beyşehir station, while dissimilar results emerged from the methods used for other stations. Although it was concluded that there was no trend according to the MK approach at Konya Airport, Beyşehir, and Cihanbeyli stations, it was observed that there was an increasing trend according to the ITA approach. Considering this situation, there is a need to re-evaluate the snow loads for Konya Airport, Beyşehir, and Cihanbeyli in the current TS EN 1991-1-3 standard [26], which determines the snow loads in our country.

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