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Use of the Daily Temperatures in Estimating the Climate Change Indices for 1985-2023 in Saudi Arabia

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Abstract

Climate change poses significant economic, social, political and environmental challenges, with impacts more effective on dry areas. This research presents an analysis of daily temperatures used in determining the trends of maximum and minimum temperatures (Tx and Tm). The data was collected from NCM (National Center of Meteorology) for 39 years (1985-2023). This study addresses data by analyzing the variability by using the coefficient of variation (CV), homogeneity by applying three tests (Pettit, SNHT and Buishand). The Semi-average and Man-Kendall methods were used to analyze long-term trends in temperature in 10 regions of Saudi Arabia from 1985 to 2023 using Mann-Kendall test. The results of (Tx) frequency analysis showed that the temperature from 10˚C to 20˚C is the main class at Abha, from 15˚C to 25˚C at Riyadh and Yanbu, from 20˚C to 30˚C at seven stations during 1985-2023. The (Tm) from 20˚C to 30˚C is the main class at Rafha and Al Hassa, from 15˚C to 25˚C at Al Jouf and Al Bahah, and the class (10˚C - 20˚C) at Qurayate and Abha. The spatial variability reveals that the maximum Temperature (Tx) higher than 30˚C appears in Al Hassa, Yanbu, Riyadh, Rafha and Tabouk, while the (Tx) lower than the 30˚C appears at the northern stations and Assir. The lower minimum temperatures (Tm) are greater than 20˚C in Eastern Province) and (Western coast), but the minimum temperatures ranged between 15˚C and 18˚C were recorded in different regions. From Pettit's test, the computed p-value of maximum daily temperatures (Tx) is greater than the significant level (alpha: 0.05) at the total of stations, except Turayf. The results of SNHT test also consistent with the results of Pettit's test and indicate the homogeneous data at all stations. The results of Buishand's test confirmed the results of SNHT test. The results of the T-student test revealed three and seven insignificant increased trends and seven insignificant decreased trends of maximum temperatures, respectively. The results of the semi-averages also showed four and three insignificant decreased and increased trends of the minimum daily temperature, respectively. However, the minimum temperatures showed the significant and increased trend in Abha, Al-Ahsa and Tabuk. This study presents the spatial variation of daily temperatures using the statistical tests for analyzing the data recorded during the period 1985-2023. The integrated employment of the statistical methods and gives more accurate results about climate change indicators over Saudi Arabia.

Keywords

Maximum Daily Temperatures, Minimum Daily Temperature, Homogeneity Test, Variations, Trends, T-Student Test, Mann-Kendall Test, Saudi Arabia

1. Introduction

For better understanding of the climate change, the present paper aims to analyze three temperature indicators selected by Climpact and also recommended by the ETCCDI (Zhang et al., 2011). These daily temperatures play an important role in assessing and detecting the climatic change over the Globe. Temperature variations influence various human activities, especially agriculture, architecture, power generation and use, including electrical power for eating and cooling; melting of snow and the effects of freezing and icing on transportation systems (Rehman & Al-Hadhrami, 2012). Based on observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level, the Intergovernmental Panel on Climate Change (IPCC) revealed in 2007 that the warming that has occurred since the mid-20th century is very likely a result of human activities and the warming of the climate system is now "unequivocal".

Temperature changes over the years have been studied for many countries. The minimum temperature increased over the period 1951-1990 by 0.84˚C compared to only 0.28˚C increase in maximum temperatures (Karl et al., 1993). In the east of Mediterranean, an increased trend at 99% confidence was found in Malta and Tripoli and a negative at 95% confidence level in Amman (Hasanean, 2001). In Türkiye, mean, maximum and minimum surface air temperatures recorded at 70 climatic stations during the period from 1929 to 1999 revealed spatial and temporal patterns of long-term trends, change points, significant warming and cooling periods and linear trend rates per decade (Türkeş et al., 2002). The daily temperature series (1901-1998) from 11 sites in central and southern Europe, analyzed by (Domonkos et al., 2003). revealed a large long-term fluctuation in the frequencies of both winter extreme cold and summer extreme warm events during the 20th century. Estimates are that the world is warming 0.6˚C ± 0.2˚C over 100 years (Folland et al., 2001) and (Nicholls & Collins, 2006). In Spain, the analysis of mean, minimum and maximum temperatures data from 171 stations on monthly, seasonal, and annual time scales shows the increase trends in all months of the year and the annual series (Del Rio et al., 2007). In Switzerland, the analyzed long-term temperature trends based on 12 series of monthly data (1901-2000) showed mean decadal trends of +0.135˚C during the 20th century and +0.57˚C for the last decade only (Rebetez & Reinhard, 2008).

In the same context, many studies were edited in the Arab countries. In Barain, (Elagib & Abdu, 1997) demonstrated climate variability by alternate hot-dry and cool-wet events. In Kuwait, (Nasrallah et al., 2004) investigated the incidences of heat waves, hot days, very hot days and extremely hot days during the warm seasons (May-August) from 1958 to 2000. They concluded that the extremely high temperatures in the warm season were due to the changes in the regional circulation pattern. Signals of climate trends such as warming in maximum temperature, more statistically significant warming in minimum temperature, decreasing trends in daily temperature range and statistically insignificant decreasing precipitation trends were also detected in Jordan (Freiwana & Kadioglu, 2008). Climate change is an essential component for strategic water resource management in arid and semi-arid countries, including Saudi Arabia. In Saudi Arabia, (Alkolibi, 2002) found that an increase in temperature and decrease in precipitation could have a major negative impact on agriculture and water supplies. The linear and Mann-Kendall analysis of temperature and temperatures future trends for several regions in Saudi Arabia, showed an increase of temperature in all regions and decrease of temperatures in many regions. The outputs of the NCAR Community Climate System Model obtained for three emission scenarios (RCP8.5; RCP6; and RCP2.6) for the assessment periods of 2025-2044, 2045-2064 and 2065-2084 respectively, and compared with the average values from the reference period (1986-2005) showed an increase from 1986 to 2005 in all regions. For RCP8.5, increase of temperature are in the ranges of 0.8˚C - 1.6˚C, 0.9˚C - 2.7˚C and 0.7˚C - 4.1˚C during 2025-2044, 2045-2064 and 2065-2084 respectively (Tarawneh & Chowdhury, 2018). An extreme temperature trend was reported in the west coast of Saudi Arabia using the linear and Mann-Kendall tests (Rehman & Al-Hadhrami, 2012). This study showed an increase in summer temperature and the number of hot days per year. This study applied the regional climate model (PRECIS) for the predictions showed the increase of temperature by 0.65˚C per decade while the central region to the coast of the Red Sea would be affected by the increased extreme temperatures events (Almazroui, 2013). An increase of temperature by 1.8˚C - 4.1˚C was showed in different regions of Saudi Arabia, which was consistent to the global positive trends (Chowdhury & Al-Zahrani, 2013). This study presents long-term temperature trend analysis by utilizing daily time series data collected over 1985 to 2023 for 10 meteorology stations located in different regions of Saudi Arabia. The trend significances were analyzed using four methods which are the semi-averages, moving averages, T-student and Mann-Kendall.

2. Data and Methodology

2.1. Study Area

The selected weather stations were located over Saudi Arabia as shown in the map of Figure 1. The study area is characterized by a diversity of relief features between coastal plains, inland valleys, and mountain ranges, extending at altitudes ranging from sea level to approximately 3000 meters in the south western region. This region includes the Red Sea Plain (Tihama Plain), which is bordered by the Red Sea to the west and the Western Highlands to the east, as well as the Western Highlands region (the Hijaz Mountains), which is considered one of the most distinguished natural regions. The selected weather stations are extended between latitudes 12˚ and 32˚ North and longitudes 36˚ and 51˚ East (Table 1 and Figure 1).

Table 1. Name, location, elevation, and the available data period.

Region	Station Name	Latitude (N)	Longitude (E)	Elevation (m)	Available data
Assir	Abha	18.22	42.65	2093.3	1985-2023
	Al Bahah	20.28	41.63	1651.9	1985-2023
Northern region	Tabouk	28.37	36.60	768.1	1985-2023
	Al Jouf	29.78	40.08	668.7	1985-2023
	Qurayate	31.40	37.27	503.9	1985-2023
	Turayf	31.68	38.73	852.4	1985-2023
Eastern Province	Al Hassa	25.42	49.63	143.0	1985-2023
Northern borders	Rafha	29.62	43.48	444.1	1985-2023
Central region	Riyadh	24.92	46.72	613.6	1985-2023
Western coast	Yanbu	24.13	38.05	10.4	1985-2023

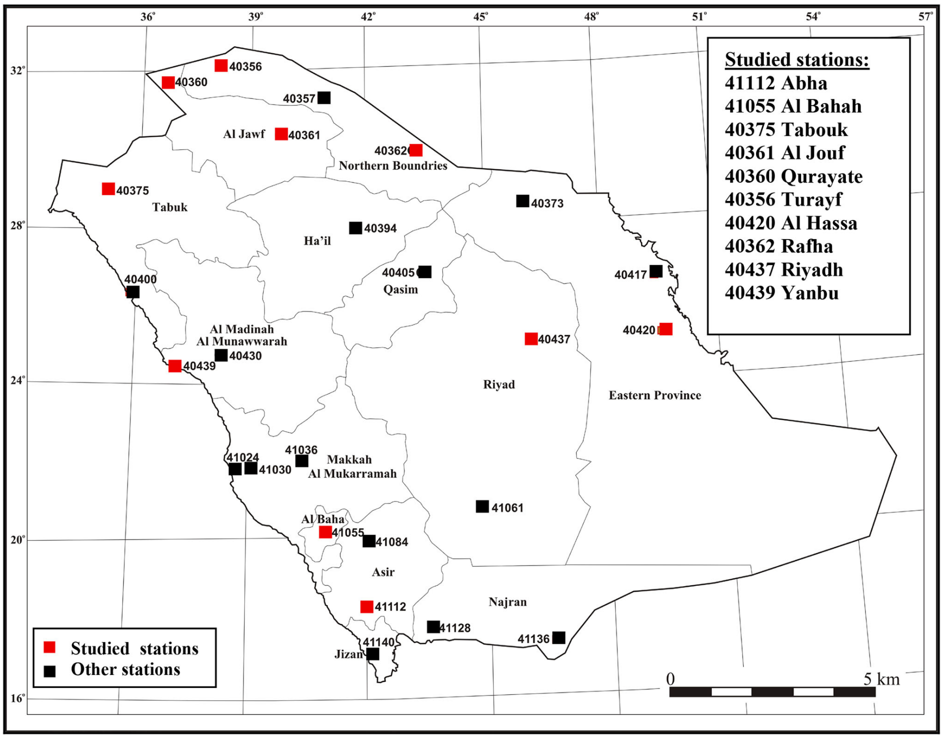

Figure 1. Geographic location of the study area and selected meteorology stations.

Saudi Arabia is characterized by a semi-arid environment with high temperature variability, low annual temperatures, no natural perennial flow and limited groundwater reserves (Chowdhury & Zahrani, 2013). The policies on agriculture, industry and water resources are greatly affected by the climatic condition. Summers in the central region are extremely hot and dry, ranging from 27˚C to 43˚C in the inland areas and 27˚C to 33˚C in coastal areas.

In winter, the temperature ranges between 8˚C to 20˚C in the interior parts while higher temperatures (19˚C - 29˚C) have been recorded in the coastal areas of Red Sea. The average annual temperatures in most parts of the country are below 150 mm throughout the year except the southwestern part where the temperatures occur between 400 - 600 mm/year. The data used in this study is the observed daily temperature records were compiled from 10 stations from the Presidency of Meteorology and Environment (PME) in SA, where cover most parts of SA (**Table 1** and **Figure 1**). These stations were chosen for the quality and consistency of their recordings. **Table 1** illustrates the names, location (latitude and longitude), elevation, and the available period for every station. The observed dataset was used for studying the variability and the trend of daily maximum and minimum temperatures.

The study incorporates daily maximum and minimum values of temperature in the present analyses. The variability of daily data for 1985-2023 was discussed and the extreme values were identified using the ascending rank available in Excel software. The Homogeneity of the time series using Xlstat software, frequency analysis, descriptive statistics were calculated using the function tools also available in SPSS and Excel software. Also, these data were used for trend analysis using the T-student and Mann-Kendall methods.

2.2. Statistical Analysis

2.2.1. Collect of Data

Daily maximum and minimum temperature (1985-2023) were collected from the National NCM (National Center of Meteorology) for 39 years (1985-2023) and subjected to rigorous quality control. The dataset and a time series of more than 30 years to analyze weather data are in line with the World Meteorological Organization's (WMO) convention of using 30 years of data to characterize the climate of an area (Yirga, 2017). Therefore, 39 years of meteorological data from 10 weather stations were used. The temperature data was selected because of the significant sensitivity of the spatial variations (**Table 1** and **Figure 1**). The stations under study cover most parts of SA. These stations were chosen for the quality and consistency of their recordings. **Table 1** illustrates the names, location (latitude and longitude), elevation, and the available period for every station. **Table 2** shows the yearly distribution of maximum and minimum daily temperatures recorded from 1985 to 2023.

2.2.2. Methods of Data Analysis

In this study, the XLSTAT software was used along with Excel spreadsheet tools to analyze temperature variability, homogeneity and trends (Figure 2). Descriptive statistics and non-parametric tests were computed to detect trends, directions, magnitudes, and inter-annual variability. Some measures of Central Tendency and Dispersion were calculated. Descriptive statistics such as minimum, maximum, mean, standard deviation and coefficient of variation using a simple Excel spreadsheet. The observed dataset was used for studying the variability, homogeneity and frequency of daily maximum and minimum temperatures. The Semi-Averages method, Mann-Kendall test and Sen's slope estimator were used for trend detection in the time series (Abegaz & Endalew, 2020).

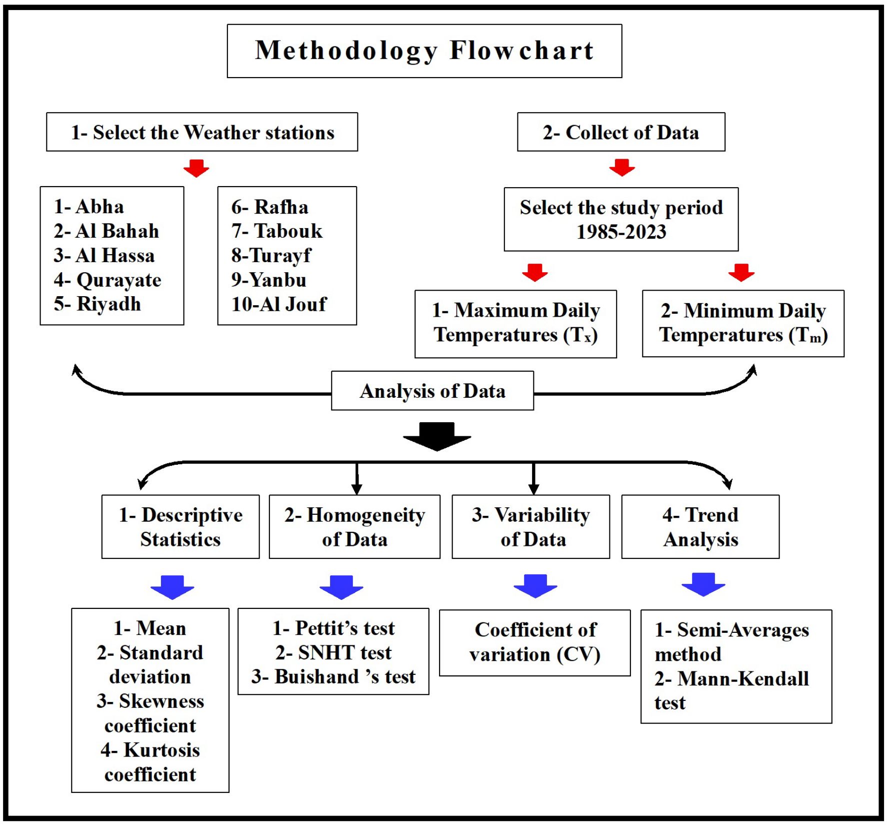

Figure 2. Flowchart of study methodology.

2.2.3. Homogeneity of the Data

To examine the homogeneity of the observed data, the temperature data collected from each station was arranged in time series (1985-2023). Homogeneity was assessed at a 95% confidence level with null hypothesis (H0, data are homogeneous), and alternative hypothesis (Ha, data are non-homogeneous) using XLSTAT software. The methods used in this study are discussed below.

1) Pettit's test

The Pettitt's test (Pettitt, 1979) is a nonparametric test adapted from the rank-based Mann-Whitney test that allows identifying the point at which the shift occurs in a time series. The break is detected near the year m, when the estimated value (X_E) exceeds the critical value:

$$X_E = \max\left|X_d\right| \text{ for } 1 \le d \le n$$

where X_d is the Mann-Whitney statistic and can be calculated as:

$$X_d = 2\sum_{i=1}^{d} r_i - d(n+1)$$

$$T_O = \frac{T(n)^2 n}{T(n)^2 (n-2)}$$

where $d = 1, 2, 3, 4, \cdots, n$ is the number of years, r_i the rank of ith observation.

The Ho is rejected if p-value is above the alpha value 0.05.

Table 2. The yearly data of maximum and minimum daily temperature.

Year	Abha		Al Bahah		Tabouk		Yanbu		Al Jouf		Al Hassa		Qurayate		Rafha		Riyadh		Turayf	
	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm	Tx	Tm
1985	31.1	2.2	35.6	5.0	43.3	0.0	45.0	10.0	48.9	−1.1	47.2	4.4	44.4	−2.8	46.1	−2.2	46.1	2.8	41.7	−2.8
1986	31.7	0.0	38.9	2.8	41.7	−1.1	45.6	9.4	42.2	−1.1	55.6	2.8	42.2	−2.2	45.6	−1.1	46.1	2.2	41.1	−3.9
1987	32.8	1.1	38.9	4.4	42.8	0.0	45.6	8.9	45.0	0.0	48.9	3.9	47.2	−1.1	48.9	−1.1	47.2	2.8	43.9	−2.2
1988	32.2	3.3	38.9	1.1	41.7	0.0	46.1	7.8	43.9	0.0	47.2	0.0	42.2	−2.2	46.1	−1.7	46.1	2.2	40.0	−1.1
1989	31.7	2.8	37.2	2.2	42.8	−7.2	46.7	7.2	42.8	−5.0	47.2	0.0	41.1	−5.0	47.8	−3.9	46.1	0.0	40.0	−6.1
1990	36.1	0.0	38.9	3.9	42.2	0.0	45.0	10.0	47.8	−2.2	47.2	2.8	42.2	−6.1	46.1	−1.7	46.1	1.7	40.0	−5.0
1991	32.2	5.0	38.9	2.8	42.2	−1.1	46.1	8.9	45.0	−3.9	47.2	5.0	42.2	−2.8	47.2	−2.8	46.1	3.9	40.0	−2.8
1992	31.1	0.0	35.0	1.1	41.1	−2.8	47.8	7.2	42.8	−5.0	47.2	1.1	42.2	−4.4	43.9	−6.1	45.0	0.0	41.1	−7.8
1993	32.2	0.0	36.1	0.0	42.2	−2.2	45.6	8.3	42.8	−5.0	47.8	2.8	43.9	−7.2	46.1	−3.9	45.0	0.0	40.0	−5.0
1994	32.8	2.2	37.2	7.8	42.8	0.0	45.0	10.0	43.9	−2.8	47.8	2.2	43.9	−2.8	46.1	−2.8	45.0	2.2	42.2	−2.2
1995	32.2	4.4	37.2	7.2	42.8	0.0	47.2	10.6	45.6	1.1	47.2	6.1	42.8	−1.1	45.0	2.8	45.0	3.9	42.2	−1.1
1996	32.8	0.0	37.8	8.9	42.8	0.0	47.8	8.9	45.0	1.1	47.8	0.0	43.9	−1.1	47.2	2.2	45.0	6.7	42.8	−1.1
1997	32.8	4.4	37.2	3.9	41.1	−3.9	43.9	8.9	42.2	−2.8	48.3	2.8	41.1	−3.9	43.9	−2.8	47.2	5.0	38.3	−5.0
1998	32.8	2.8	37.8	5.6	43.9	0.0	48.9	7.2	46.1	1.1	48.9	3.9	45.0	−2.2	47.8	−1.1	46.1	2.8	43.9	−2.8
1999	36.1	2.8	37.8	6.1	42.2	−1.1	47.8	8.9	43.9	0.0	48.3	6.1	42.2	−5.0	46.1	1.1	46.7	6.1	42.2	−2.8
2000	32.8	5.0	37.2	7.8	45.0	−1.7	47.2	5.0	45.0	0.0	49.4	5.0	46.1	−3.9	47.2	0.6	46.1	5.0	42.8	−3.9
2001	32.2	2.2	37.2	5.0	43.9	0.0	47.8	10.0	47.2	0.0	48.3	3.9	42.8	−3.9	47.2	−1.1	47.2	2.2	42.8	−2.8
2002	32.8	5.6	37.8	5.0	42.2	−1.1	47.8	8.9	43.3	1.1	49.4	2.8	43.9	−2.2	47.2	0.0	47.2	3.9	41.1	−2.8
2003	32.2	1.0	37.2	2.0	49.0	1.0	49.0	2.0	46.1	−1.1	48.3	3.9	42.2	−1.1	47.2	1.0	48.0	0.0	43.0	−2.2
2004	32.2	1.0	14.0	14.0	13.0	10.0	22.0	21.0	9.0	8.0	13.0	12.0	8.0	5.0	10.0	9.0	14.0	13.0	5.0	3.0
2005	32.2	1.0	14.0	14.0	−17.8	−17.8	22.0	21.0	9.0	8.0	13.0	12.0	−17.8	−17.8	−17.8	−17.8	47.6	0.0	5.0	3.0
2006	32.2	1.0	14.0	14.0	−17.8	−17.8	44.3	8.9	42.4	0.0	40.2	5.4	−17.8	−17.8	18.0	18.0	46.6	0.8	36.0	−2.0
2007	26.3	8.8	35.0	8.9	33.2	2.8	44.3	8.9	42.4	0.0	40.2	5.4	35.8	1.0	45.0	0.5	43.0	3.9	36.0	−2.0
2008	33.2	4.0	36.7	3.0	43.0	−4.0	46.0	9.9	46.0	−5.0	48.5	0.9	44.0	−9.0	46.0	−5.0	46.0	−2.0	42.0	−8.0

Continued

2009	31.1	6.1	35.0	5.0	40.0	2.2	43.0	12.2	42.0	1.1	43.9	5.0	38.9	−2.8	41.0	−1.1	45.0	2.8	40.0	−3.0
2010	29.0	4.0	33.0	7.0	40.0	2.0	41.0	10.0	40.0	3.0	39.0	7.0	36.0	1.0	44.0	1.0	43.0	5.0	36.0	1.0
2011	32.8	0.0	37.8	5.0	43.9	2.0	47.8	10.0	46.1	0.0	50.0	6.0	45.0	−6.0	47.8	−2.0	47.8	7.8	43.9	−3.0
2012	34.0	4.0	38.0	5.0	44.0	−1.0	48.0	9.0	46.0	−1.0	51.0	2.0	53.0	−6.0	48.0	−3.0	47.3	−1.1	44.0	−12.0
2013	34.0	5.0	38.0	5.0	44.0	−2.0	47.0	3.0	45.0	−2.0	49.0	5.0	44.0	−6.0	46.0	−2.0	45.6	−0.5	42.0	−5.0
2014	33.0	5.0	36.0	6.0	44.0	1.0	48.0	12.0	45.0	1.0	49.0	6.0	43.0	−4.0	47.0	−1.0	45.0	10.0	42.0	−4.0
2015	33.0	5.0	37.0	5.0	44.0	−1.0	50.0	4.0	46.0	−8.0	50.0	5.0	45.0	−2.0	47.0	−3.0	45.0	4.0	49.0	−4.0
2016	36.0	5.0	38.0	3.0	44.0	−2.0	47.0	10.0	47.0	−2.0	50.0	3.0	45.0	−6.0	48.0	−3.0	45.0	2.0	43.0	−6.0
2017	35.0	4.0	38.0	5.0	45.0	−1.0	49.0	3.0	46.0	−4.0	50.0	1.0	45.0	−8.0	47.0	−3.0	44.0	6.0	44.0	−5.0
2018	35.0	3.0	37.0	4.0	44.0	1.0	47.0	7.0	46.0	1.0	49.0	4.0	43.0	0.0	46.0	3.0	41.0	4.0	43.0	−10.0
2019	35.0	4.0	38.0	5.0	43.0	1.0	49.0	10.0	46.0	2.0	49.0	5.0	45.0	−2.0	54.0	5.0	45.0	6.0	43.0	−2.0
2020	34.0	3.0	38.0	3.0	46.0	−1.0	48.0	7.0	48.0	0.0	50.0	4.0	48.0	−2.0	51.0	−3.0	47.0	3.0	45.0	−4.0
2021	34.0	3.0	38.0	6.0	43.0	0.0	48.0	10.0	46.0	0.0	50.0	6.0	45.0	−2.0	52.0	−1.0	53.0	6.0	43.0	−3.0
1022	34.0	5.0	38.0	5.0	44.0	−1.0	48.0	9.0	46.0	−1.0	49.0	4.0	45.0	−5.0	48.0	−2.0	30.0	9.0	45.0	−6.0
2023	34.0	3.0	38.0	7.0	45.0	2.0	48.0	11.0	45.0	2.0	50.0	8.0	46.0	1.0	47.0	1.0	47.0	6.0	43.0	−1.0

2) Standard Normal Homogeneity Test (SNHT)

This test was conducted to detect significant changes by transforming the series into normal Z scores (Jarušková, 1996). In essence, this technique attempts to divide data into two phases, before $T(n)$ and after $T(n)$. If there are significant changes between the data before and after $T(n)$, then the data is considered inhomogeneous. SNHT is defined as (Alexandersson, 1986):

$$T(k) = kz_1'^2 + (n-k)z_2'^2$$

where $k = 1, 2, 3, \cdots, n$

z_1' is the mean of z-value mean series before, and z_2' is the mean of z-value after the break year to n number of observations.

The probable break year of the record is assumed to be the maximum value of $T(k)$ and can be formulated as:

$$T_n = \max\{T(k)\} \quad \text{for} \quad 1 \le k \le n$$

So, the To can be calculated usi the following relationship (1):

Ho is rejected if To is above the p-value 0.05.

3) Buishand Range Test (BRT)

The Buishand range test (Buishand, 1982) calculate the adjusted partial sums of the statistics to identify any inhomogeneities. The test can actually be used for various types of distributions, but it is more suitable for normally distributed data. The Buishand test is sensitive to breakpoints in the middle of a time series (Hawkins, 1977). The cumulative deviations test is based on the adjusted partial sums or cumulative deviations from the mean:

$$S_k^* = \sum_{n:1}^{n} \left(X_t - X' \right), \quad k = 1, 2, 3, \cdots, n$$

where S_k^* is the cumulative deviations;

X_t : the observed observation;

X' : the sample mean;

n: the number of records in the time series.

Tye rescaled adjusted partial sums (S^{**}) are obtained as:

$$S^{**} = \frac{S_k^*}{D_x}, \quad k = 1, 2, 3, \cdots, n$$

where the D_x is the standard deviation (D_x) can be calculated as:

$$D_x = \frac{\sum_{i:1}^{n} \left(X_t - X' \right)}{n}$$

The cumulative deviation test statistic (Q) is estimated as:

$$Q = \max \left| S_k^{**} \right|, \quad 0 \le k \le n$$

2.2.4. Variability of the Data

In this study, the coefficient of variation (CV) technique was used to examine the variability of Temperatures time series of the studied and calculated as follows:

$$\text{CV} = 100\sigma / Y$$

where Y is the average for N years and σ is the standard deviation.

2.2.5. Trend Analysis

The parameters of descriptive statistic were calculated by simple and known statistical methods. The magnitudes of the trends of increasing or decreasing temperatures were derived from the T-student and Mann-Kendall methods.

1) Semi-averages method

The T-student test was applied to compare the arithmetic means of two separate samples. The time series for each temperature indicator is divided into two equal parts. Then the arithmetic mean of the first part is calculated and compared to the arithmetic mean of the second part, using the T-student equation, as follows:

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{\overline{S_1}}{n_1} + \frac{\overline{S_2}}{n_2}}}$$

where:

X_1 : mean of the first part;

X_2 : mean of the second part;

$\overline{S_1}$: variance of the first part;

$\overline{S_2}$: variance of the second part;

n_1 : number of years for the first part;

n_2 : number of years for the second part.

2) Mann-Kendall test

The Mann–Kendall (MK) test as a non-parametric method proposed originally by Mann in 1945 for detecting trends in a time series without indicating whether the trend is linear or non-linear (Partal & Kahya, 2006). The Mann-Kendall test is one of the important non-linear tests widely used in many environmental and climate studies to determine the presence of potential significance in time series trends. It is one of the methods that provides a trend test and a valuable tool for examining the data trends. It was approved by the IPCC, and also suggested by the World Organization For Meteorology (WMO) to the significant trends in time series of climate and hydrological data. It will be used in this study to analyze the significant trends of annual temperatures as climate change indicator. Under Ho, the Mann-Kendall test statistic is given by the following mathematical relationship (Kendall & Gibons, 1990):

$$S = \sum_{f-1}^{n-1} \sum_{j=+1}^{n} \operatorname{sgn}\left(x_i - x_i\right) = \begin{cases} +1 & \text{for } t > 0 \\ 0 & \text{for } t = 0 \\ +1 & \text{for } t < 0 \end{cases}$$

where $X_1, X_2, \cdots, X_n$ is the sequence of measurements over time.

$$Z = \begin{cases} \dfrac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sigma} & \text{if } S < 0 \end{cases}$$

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18}$$

where:

n: time series size.

S: the Mann–Kendall test statistic.

σ: standard deviation of the data.

The Mann-Kendall test is a non-parametric test, which does not require data to be normally distributed. The other advantage of this method is its low sensitivity to abrupt breaks due to an inhomogeneous time series (Rehman & Al-Hadhrami, 2012). This test is used to analyze the statistical significance of all trends. The Mann-Kendall statistical test is a value that indicates direction (or sign) and statistical magnitude of the trend in a series.

3. Results and Discussion

3.1. Results

Before analyzing the data variability, homogeneity and trends, the distribution patterns of daily temperatures was tested using Kolmogorov-Smirnov test available in SPSS software. Based on the outputs of Kolmogorov-Smirnov test, the significance level of variance was 0.000 in the total of studied stations, indicating the data distribution different than the normal distribution.

3.1.1. Descriptive Statistics of Data

The measures of central tendency show the spatial variability of mean, standard deviation and coefficient of variation (Table 3). Table 3 illustrates the average of maximum and minimum air temperature during the studied period for each station. It reveals that the maximum Temperature (Tx) higher than 30˚C appears in the different regions of SA at Al Hassa, Yanbu, Riyadh, Rafha and Tabouk, respectively, while the lower values of Tx lower than the 30˚C appear at the northern stations and Assir. The lower (Tm) minimum temperatures are greater than 20˚C in Al Hassa (Eastern Province) and Yanbu (Western coast). The minimum temperatures ranged between 15˚C and 18˚C were recorded in different regions with 15.2˚C, 16.0˚C, 16.5˚C, 16.6˚C and 17.0˚C in respectively Tabouk, Al Jouf, Rafha, Al Bahah and Riyadh. However, Qurayate, Turayf and Abha were characterized by the minimum daily temperatures reaches to 12.0˚C, 12.5˚C and 12.9˚C, respectively. Descriptive statistics for the daily minimum temperature series from 1985 to 2023 are summarized in Table 3. The average of daily minimum temperature in the study area ranged from −12.0˚C at Turayf to 21.0˚C at Yanbu, with a mean minimum temperature of −3.5˚C to 9.0˚C, respectively. The maximum daily temperatures were characterized by a Skewness negative values ranged from (−4.156 at Riyadh) to (−0.985 at Abha) for the maximum daily temperatures (−2.141 at Tabouk, −1.613 at Qurayate and −2.141 at Tabouk) for the minimum temperature indicate that the data are asymmetrically distributed and skewed to the right. However, the Skewness positive values for minimum daily temperatures observed at Abha, Al Bahah, Yanbu, Al Jouf, Al Hassa, Rafha and Riyadh vary from 0.228 to 1.364 indicate that the data are asymmetrically distributed and skewed to the left. In the other hand, the Kurtosis values for maximum and minimum daily temperatures are positive in the total of studied stations. In the total of studied stations, the Kurtosis values for maximum daily temperatures and at for the minimum daily temperatures at Tabouk, Yanbu, Qurayate and Rafha were greater than 3.0 and indicate that the distribution has more peaked center than a normal distribution. In the rest of the stations, the Kurtosis values for the minimum daily temperatures vary from 0.008 at Abha and 2.099 at Al Hassa and indicate a platykurtic shape.

From Table 3, the coefficients of variation ranged from 0.25 to 0.50 indicate the moderate variability of minimum daily temperatures (Tm) at Abha, Al Bahah, Al Hassa, Yanbu, Riyadh and Tabouk. However, the coefficients of variation higher than 0.50 revealed the high variability of (Tm) at Qurayate, Rafha, Al Jouf and Turayf. In the other hand, the coefficients of variation ranged from 0.16 to 0.28 indicate the low variability of maximum daily temperatures (Tx) at Abha, Al Bahah, Al Hassa, Yanbu and Riyadh. However, the coefficients of variation higher than 0.28 revealed the moderate variability of (Tx) at Tabouk, Qurayate, Al Jouf, Rafha and Turayf (Figure 2).

Table 3. Descriptive statistics of the temperatures for 1985-2023.

	Statistics	T_{min}	T_{max}		Statistics	T_{min}	T_{max}		Statistics	T_{min}	T_{max}		Statistics	T_{min}	T_{max}		Statistics	T_{min}	T_{max}
	X'	12.9	26.4		X'	20.1	35.3		X'	15.2	30.1		X'	21.6	35.2		X'	16.0	29.7
	Sd	4.6	5.5		Sd	7.8	9.4		Sd	7.6	8.3		Sd	5.5	5.5		Sd	8.3	9.6
	CV	0.35	0.21		CV	0.39	0.27		CV	0.50	0.28		CV	0.25	0.16		CV	0.52	0.32
	Variance	20.8	30.0		Variance	61.2	87.8		Variance	58.2	69.3		Variance	30.0	30.6		Variance	68.6	93.0
Abha	Maximum	30.0	48.0	Al Hassa	Maximum	92.6	50.8	Tabouk	Maximum	33.0	46.4	Yanbu	Maximum	35.4	49.6	Al Jouf	Maximum	35.6	48.0
	Minimum	−5.0	8.0		Minimum	−2.3	3.8		Minimum	−4.0	3.0		Minimum	4.7	15.0		Minimum	−7.0	0.0
	Range	35.0	40.0		Range	94.9	47.0		Range	37.0	43.4		Range	30.7	34.6		Range	42.6	48.0
	Skewness	0.228	−0.985		Skewness	0.955	−3.455		Skewness	−2.141	−3.544		Skewness	1.364	−3.577		Skewness	0.467	−3.868
	Kurtosis	0.008	3.650		Kurtosis	2.099	12.211		Kurtosis	7.904	12.071		Kurtosis	4.881	13.029		Kurtosis	1.971	14.738
	X'	16.6	29.5		X'	12.1	28.7		X'	16.5	31.5		X'	17.8	32.7		X'	12.3	26.6
	Sd	5.6	5.8		Sd	7.3	9.1		Sd	8.4	10.3		Sd	7.4	9.0		Sd	7.7	9.5
	CV	0.34	0.20		CV	0.60	0.32		CV	0.51	0.33		CV	0.42	0.27		CV	0.63	0.36
	Variance	31.5	33.3		Variance	52.8	82.4		Variance	70.8	105.8		Variance	54.9	80.2		Variance	59.6	91.1
Al Bahah	Maximum	30.0	48.0	Qurayate	Maximum	35.0	49.0	Rafha	Maximum	36.0	52.0	Riyadh	Maximum	36.1	48.2	Turayf	Maximum	30.0	48.0
	Minimum	−5.0	3.0		Minimum	−9.0	2.0		Minimum	−5.8	5.2		Minimum	−5.4	2.5		Minimum	−8.0	0.7
	Range	35.0	45.0		Range	44.0	47.0		Range	41.8	46.8		Range	41.5	45.7		Range	38.0	47.3
	Skewness	1.242	−3.094		Skewness	−1.613	−3.344		Skewness	0.649	−3.821		Skewness	0.736	−4.156		Skewness	−0.449	−3.651
	Kurtosis	2.009	8.467		Kurtosis	4.641	10.768		Kurtosis	8.014	15.594		Kurtosis	0.947	20.027		Kurtosis	1.716	13.544

The highest CV values can be attributed to the following interactions of several air depressions affecting SA (Al-Mutairi et al., 2023):

1) The Mediterranean cyclones traveling SA during winter from west to east, in association with upper air troughs and active subtropical jet, as well as the polar jet, causing rainfall during their traveling over the SA.

2) The second important pattern is the interaction between the westerly frontal troughs transporting cold air from the northwest of Europe and the southerly moist warm air coming from Somalia and Sudan. The convergence of these interactions products a huge amount of cloud over SA.

3) Near the end of the winter season (February) Finally, weather activity is strong over the eastern Mediterranean, where the secondary traveling depressions (secondary from the Mediterranean cyclones) are frequently linked with sandstorms might arrive and affect our region. Occasionally, these secondary depressions cause heavy rainfall in February and March, when the associated cold air meets the hot, moist southerly air.

4) The secondary travelling depressions of Mediterranean cyclones affecting SA in the end of winter season (February) cause a strong weather activity in eastern Mediterranean and frequently linked with sandstorms might affect SA. Occasion-

ally, these secondary depressions cause heavy rainfall in February and March, when the associated cold air meets the hot, moist southerly air.

3.1.2. Homogeneity Test Results

To examine the homogeneity of the observed data, three tests were used (Pettit, 1979), Standard Normal Homogeneity Test (Alexandersson, 1986) and Buishand Range Test (Buishand, 1982). The results obtained are shown in **Table 4** for (Tx) and **Table 5** for (Tm).

From Pettit's test, the computed p-value of Maximum daily temperatures (Tx) is greater than the significant level (alph: 0.05) at the total of stations, except Turayf (**Table 4**). The results of SNHT test also consistent with the results of Pettit's test, with p-value ranged between 0.230 at Al Hassa and 0.777 at Abha. These p-values are greater than the critical value 0.05 and indicate the homogeneous data at all stations. The results of Buishand's test confirm the results of SNHT test with p-values ranged between 0.107 at Turayf and 0.913 at Tabouk. So, the (Tx) data recorded from 1985 to 2023 is homogeneous in the studied stations.

Table 4. Results of homogeneity tests of minimum daily temperatures data for 1985-2023.

Station	Pettit's test			SNHT test			Buishand's test		
	K	p-value	t	T0	p-value	t	Q	p-value	t
Abha	16.0	0.931	1986	1.463	0.777	1986	2.075	0.732	1989
Al Bahah	23.0	0.249	1991	3.333	0.417	1991	3.257	1.196	1991
Tabouk	6.0	0.923	1985	2.769	0.419	1985	1.109	0.913	1987
Yanbu	4.0	0.665	1985	1.195	0.649	1985	1.406	0.580	1987
Al Jouf	5.0	0.995	1985	2.358	0.429	1985	1.086	0.805	1989
Al Hassa	15.0	0.844	1987	4.359	0.230	1986	3.121	1.124	1987
Qurayate	7.0	0.257	1987	2.320	0.397	1987	2.043	0.132	1987
Rafha	6.0	0.673	1986	1.553	0.549	1986	1.576	0.507	1986
Riyadh	3.0	0.661	1987	1.000	0.665	1987	1.342	0.665	1987
Turayf	9.0	<0.0001	1987	3.158	0.428	1987	2.384	0.107	1987

From Pettit's test, the computed p-value of Minimum daily temperatures (Tm) varies from 0.126 at Al Bahah and 0.950 at Tabouk and are greater than the critical value (alph: 0.05) at the total of stations, indicating the homogeneous data in all stations (**Table 5**). The results of Buishand's test are not significant from the results of Pettit's test, with p-values greater than the critical value 0.05 at all stations, except Al Bahah. The p-values vary from 0.102 at Rafha to 0.980 at Abha, indicating the homogeneous data of daily minimum temperatures recorded from 1985 to 2023. In contrast to the results of SNHT test show the p-values ranged from 0.164 at Al Jouf and 0.961 at Abha. The SNHT's p-values are greater than the critical value 0.05 at all stations, except Al Bahah, Rafha and Riyadh.

Table 5. Results of homogeneity tests of maximum daily temperatures data for 1985-2023.

Station	Pettit's test			SNHT test			Buishand's test		
	K	p-value	t	T0	p-value	t	Q	p-value	t
Abha	10.0	0.139	1991	0.989	0.561	1995	1.204	0.988	1991
Al Bahah	27.0	0.126	1993	8.061	<0.0001	1993	4.448	0.021	1993
Tabouk	15.0	0.950	1993	1.278	0.757	1993	1.816	0.859	1988
Yanbu	27.0	0.919	1993	2.456	0.660	1993	2.455	0.496	1993
Al Jouf	20.0	0.566	1994	4.222	0.164	1994	2.771	0.337	1994
Al Hassa	13.0	0.539	1987	1.758	0.719	1995	1.705	0.848	1987
Qurayate	18.0	0.754	1994	2.663	0.504	1994	2.440	0.520	1993
Rafha	20.0	0.566	1994	7.408	0.008	1994	3.676	0.102	1994
Riyadh	19.0	0.659	1994	5.502	0.050	1994	3.163	0.188	1994
Turayf	22.0	0.349	1993	3.254	0.382	1993	2.826	0.354	1993

3.1.3. Frequency Analysis of Daily Temperatures

The results of (Tx) frequency analysis showed that the main class from 10˚C to 20˚C constitute 60.2% of the (Tx) observed at Abha (Table 6 and Figure 3).

Table 6. Frequency of averages of minimum daily temperatures in selected stations.

Station		Maximum daily temperature (˚C)							Total
		Less 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	More 30	
Abha	Number	**85**	**1424**	**4000**	**4569**	**3231**	**569**	**356**	**14235**
	%	0.6	10.0	28.1	32.1	22.7	4.0	2.5	**100**
Al Bahah	Number	**28**	**268**	**2047**	**3182**	**3343**	**4996**	**370**	**14235**
	%	0.2	1.9	14.4	22.4	23.5	35.1	2.6	**100**
Tabouk	Number	**1424**	**1609**	**1765**	**1865**	**2164**	**4399**	**1011**	**14235**
	%	10.0	11.3	12.4	13.1	15.2	30.9	7.1	**100**
Yanbu	Number	**13**	**412**	**2462**	**3584**	**6332**	**1**	**1431**	**14235**
	%	0.1	2.9	17.3	25.2	44.5	0.0	10.1	**100**
Al Jouf	Number	**880**	**1960**	**1791**	**1778**	**2006**	**4838**	**982**	**14235**
	%	6.2	13.8	12.6	12.5	14.1	34.0	6.9	**100**
Al Hassa	Number	**157**	**1192**	**2788**	**3087**	**2688**	**3087**	**1236**	**14235**
	%	1.1	8.4	19.6	21.7	18.9	21.7	8.7	**100**
Qurayate	Number	**754**	**2221**	**2007**	**1865**	**2349**	**4142**	**897**	**14235**
	%	5.3	15.6	14.1	13.1	16.5	29.1	6.3	**100**
Rafha	Number	**687**	**1757**	**1739**	**1568**	**1694**	**5737**	**1053**	**14235**
	%	4.8	12.3	12.2	11.0	11.9	40.3	7.4	**100**
Riyadh	Number	**199**	**982**	**2633**	**4484**	**2164**	**3317**	**456**	**14235**
	%	1.4	6.9	18.5	31.5	15.2	23.3	3.2	**100**
Turayf	Number	**1863**	**2176**	**1863**	**1862**	**2631**	**3030**	**810**	**14235**
	%	13.1	15.3	13.1	13.1	18.5	21.3	5.7	**100**

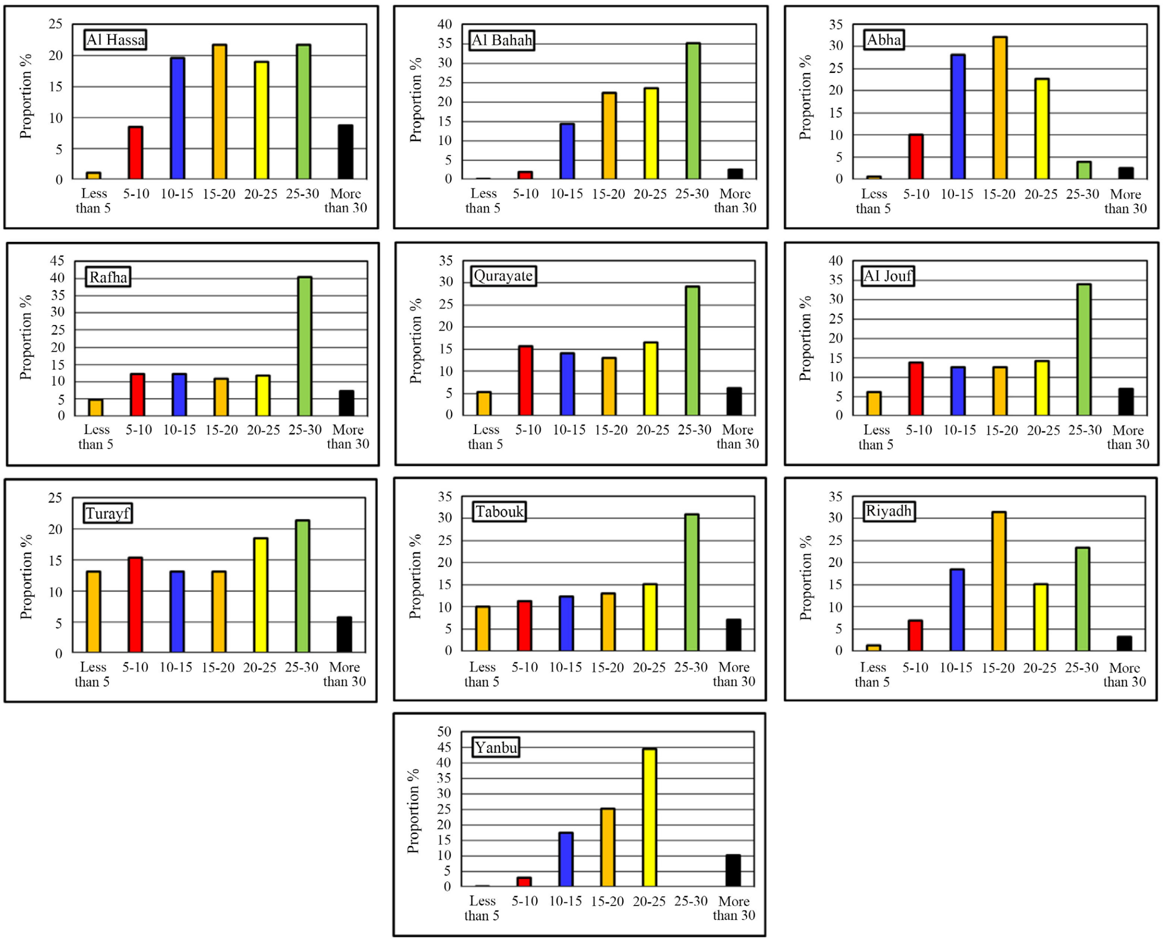

Figure 3. Proportional distribution of daily maximum temperatures for 1985-2023.

The main class from 15˚C to 25˚C composed 46.7% and 69.7% of the (Tx) recorded at Riyadh and Yanbu, respectively. However, the (Tx) from 20˚C to 30˚C is the main class at seven stations. This main class represents 39.8% to 58.6% of the (Tx), recorded during 1985-2023 at Turayf and Al Baha, respectively.

The spatial distribution of (Tm) differs from than of (Tx) (**Table 7** & **Figure 4**). So, the (Tm) (20˚C - 30˚C) are the main class at Rafha and Al Hassa with 45.4% and 50.2%, respectively. However, the (Tm) from 15˚C to 25˚C constitute the main class, wit 41.75% to 92.2% of (Tm) recorded from 1985 to 2023 at Al Jouf and Al Bahah, respectively. Finally, the class (10˚C - 20˚C) represents 44.1% and 73.3% of (Tm) observed at Qurayate and Abha, respectively.

Table 7. Frequency of averages of maximum daily temperatures in selected stations.

Station		Maximum daily temperature (˚C)							Total
		Less 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	More 30	
Abha	Number	**367**	**3254**	**5980**	**4450**	**184**	**0**	**0**	**14235**
	%	2.6	22.9	42.0	31.3	1.3	0.0	0.0	**100**
Al Bahah	Number	**114**	**1523**	**3587**	**3972**	**4883**	**157**	**0**	**14235**
	%	0.8	10.7	25.2	27.9	34.3	1.1	0	**100**

Continued

Tabouk	Number	**1692**	**2831**	**2304**	**2701**	**3853**	**840**	**14**	**14235**
	%	11.9	19.9	16.2	19.0	27.1	5.9	0.1	**100**
Yanbu	Number	**199**	**1993**	**3018**	**4541**	**3601**	**883**	**100**	**14335**
	%	1.4	14	21.2	31.9	25.3	6.2	0.7	**101**
Al Jouf	Number	**1589**	**2770**	**2102**	**2358**	**3571**	**1817**	**28**	**14235**
	%	11.2	19.5	14.8	16.6	25.1	12.8	0.2	**100**
Al Hassa	Number	**185**	**1689**	**2646**	**2327**	**2497**	**4655**	**237**	**14235**
	%	1.3	11.9	18.6	16.3	17.5	32.7	1.7	**100**
Qurayate	Number	**2890**	**3075**	**2391**	**3886**	**1879**	**114**	**0**	**14235**
	%	20.3	21.6	16.8	27.3	13.2	0.8	0	**100**
Rafha	Number	**163**	**2869**	**2301**	**2369**	**3900**	**2560**	**73**	**14235**
	%	1.1	20.2	16.2	16.6	27.4	18.0	0.5	**100**
Riyadh	Number	**3**	**2221**	**3075**	**3130**	**3102**	**2804**	**0**	**14335**
	%	0.0	15.6	21.6	22.0	21.8	19.7	0.0	**101**
Turayf	Number	**356**	**3744**	**2719**	**4271**	**2890**	**256**	**0**	**14235**
	%	2.5	26.3	19.1	30.0	20.3	1.8	0	**100**

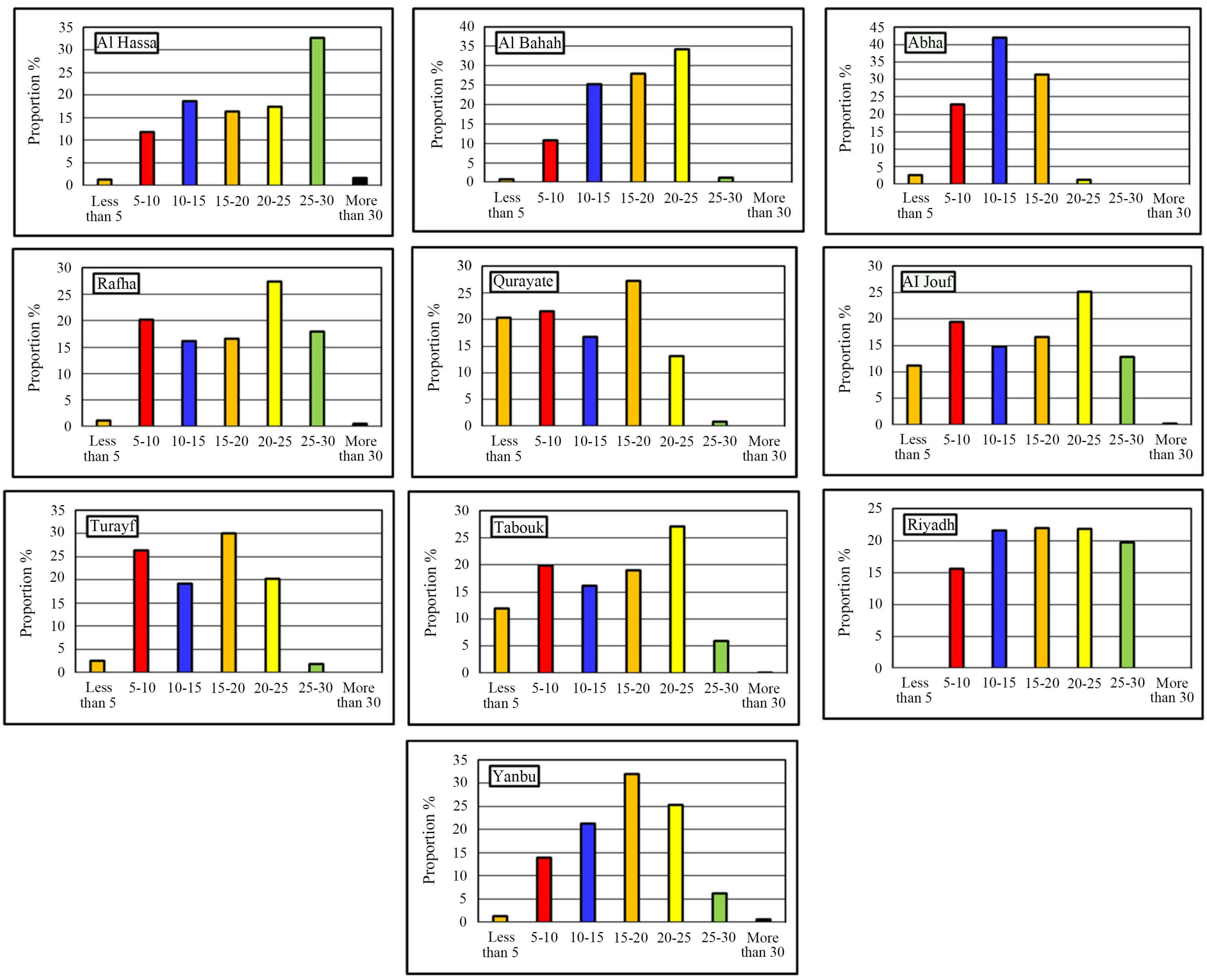

Figure 4. Proportional distribution of daily minimum temperatures for 1985-2023.

3.1.4. Trend Analysis of Daily Temperatures

The trends of daily temperatures over different years were obtained using semi-averages method, and the M-K rank tests. The findings can be analyzed as follows:

1) Semi-averages method:

The trends for the daily temperature are shown in Table 8 and Figure 4 for semi-averages method. In this method the whole data are divided into two equal parts with respect to time (20 years) with 1985-2004 for the first period and 2005-2023 for the second period. After the data has been divided into two parts, an average (arithmetic mean) of each part is obtained. We thus compute the T-student value. The computed T-student value was compared to the critical value 1.645 at freedom degree of 18 and the significance level of 0.05. The temperature trend was considered significant, when the absolute value of computed T-student is smaller than the critical value 1.645. The results of the T-student test showed three increasing and non-significant trends and seven decreasing and non-significant trends at the significance level, ranged between 0.221 in Al-Bahah and 0.888 in Qurayat, exceeding the critical value of 0.05 at the degree of freedom 18 (Table 8 and Figure 5).

Table 8. Semi-average test of maximum and minimum daily temperatures trends for 1985-2023.

	Statistic	Abha	Al Bahah	Al Hassa	Al Jouf	Qurayate	Rafha	Riyadh	Tabouk	Turayf	Yanbu
Maximum Daily Temperature (˚C)	**X1'**	32.6	36.3	46.6	42.9	41.5	44.6	44.6	41.4	39.7	45.4
	Sd1	1.3	5.4	8.1	8.2	8.0	8.2	7.3	6.9	8.3	5.7
	Var1	1.7	28.8	66.0	67.2	64.6	68.0	52.6	47.7	68.9	32.3
	X2'	33.0	34.6	45.8	43.2	43.1	44.3	44.9	41.9	40.3	45.5
	Sd2	2.3	7.4	8.8	8.5	4.6	9.7	4.4	4.1	9.1	6.1
	Var2	5.2	54.7	77.6	72.3	21.5	93.6	19.2	17.1	83.7	37.6
	t	**−0.601**	**1.269**	**0.956**	**−0.281**	**0.143**	**−0.628**	**1.167**	**0.979**	**−0.576**	**0.818**
	Sig.	**0.555**	**0.221**	**0.352**	**0.782**	**0.888**	**0.538**	**0.259**	**0.341**	**0.592**	**0.424**
		NS	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Minimum Daily Temperature (˚C)	**X1'**	2.3	4.8	3.6	−0.9	−2.8	−0.8	3.3	−0.6	−3.0	9.0
	Sd1	1.9	3.3	2.7	3.0	2.5	3.2	3.0	3.1	2.2	3.5
	Var1	3.5	10.6	7.3	8.8	6.3	10.0	9.0	9.6	5.0	12.0
	X2'	3.9	6.1	5.0	−0.3	−4.9	−1.0	3.8	−1.8	−4.0	9.3
	Sd2	2.0	3.1	2.5	3.3	5.4	6.4	3.4	5.9	3.5	3.9
	Var2	3.9	9.8	6.3	11.0	29.5	41.3	11.5	34.8	12.4	15.4
	t	**−2.280**	**−1.701**	**−3.353**	**−1.131**	**−0.341**	**−1.414**	**−1.295**	**−2.348**	**0.792**	**−0.945**
	Sig.	**0.035**	**0.092**	**0.004**	**0.273**	**0.737**	**0.174**	**0.212**	**0.030**	**0.439**	**0.357**
		S	**NS**	**S**	**NS**	**NS**	**NS**	**NS**	**S**	**NS**	**NS**

S: Significant, NS: Non Significant.

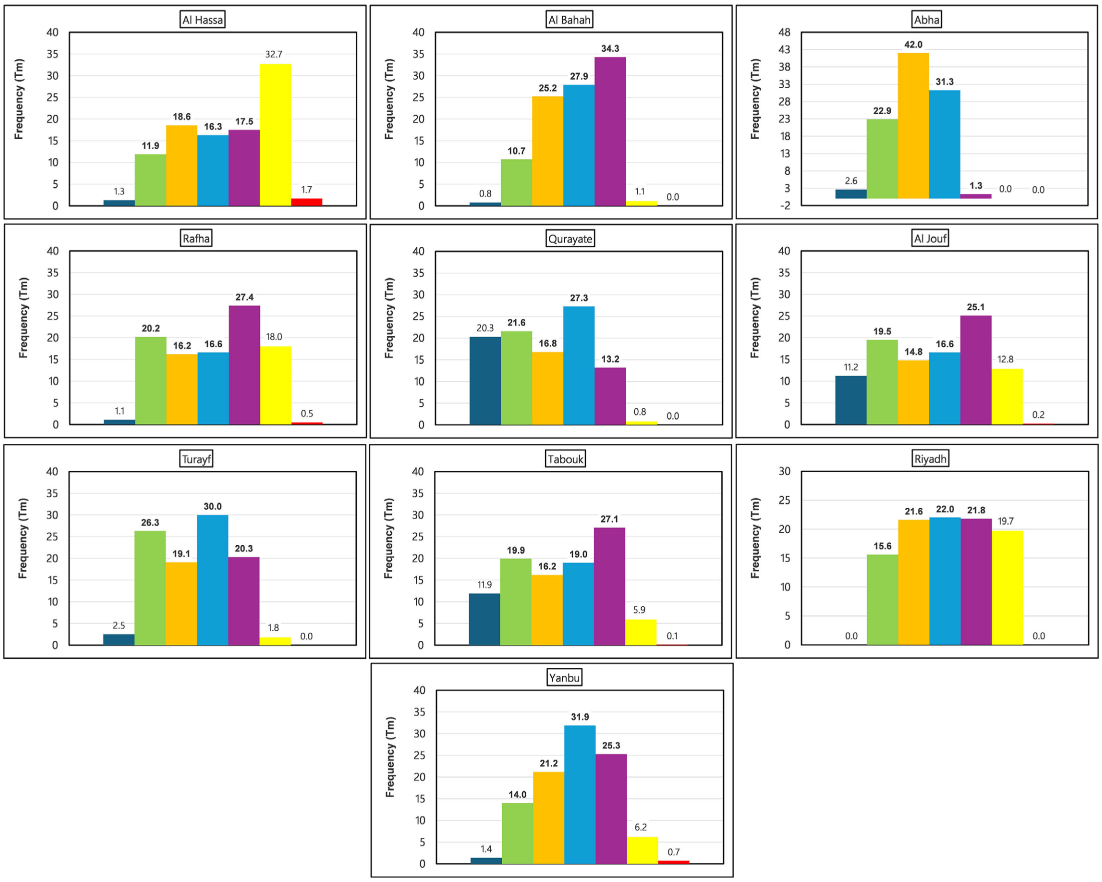

Figure 5. The trends of maximum daily temperatures in selected weather stations during 1985-2023 using the semi-averages method.

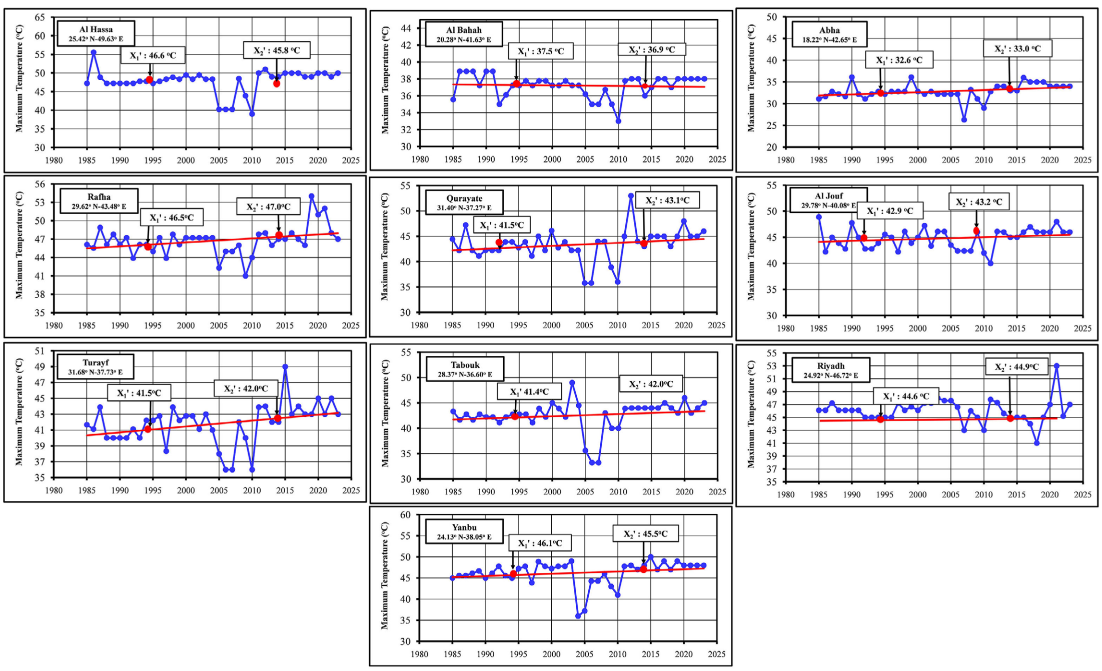

Figure 6. The trends of minimum daily temperatures in selected weather stations during 1985-2023 using the semi-averages method.

The results of this test for the semi-averages of the minimum temperatures at the degree of freedom 18, also showed four decreasing and non-significant trends amounting to 0.092, 0.273, 0.212 and 0.357 in Al-Bahah, Al-Jouf, Riyadh and Yanbu, respectively, and three increasing and non-significant trends amounting to 0.737, 0.174 and 0.439 in the Qurayate, Rafha and Turayf stations, respectively. On the other hand, the general change trends in minimum temperatures were increasing and significant at the Abha, Al-Ahsa and Tabuk stations (**Table 8** and **Figure 6**).

2) Mann-Kendall test

The Mann-Kendal test (Z), combined with Sen's slope estimator (Q) is a common statistical method used to analyze temperature trends in time series data. It asses if there is a statistically significant monotonic (increasing or decreasing) trend in the temperature data, and Sen's slope estimates the magnitude of that trend. A summary of the detailed analysis of temperature trends, as assessed using the Mann-Kendall test is presented in **Table 9**. The results indicate an overall increasing significant trend for the maximum daily temperature (Tx) in Abha, Al Hassa, Qurayate, Tabouk, Turayf and Yanbu. All observed trends of maximum daily temperatures exhibited an insignificant trend at Al Bahah (Zs 0.20), Al Jouf (Zs 1.38), Rafha (Zs 1.47) and Riyadh (Zs −0.90). The maximum daily temperature showed an increased significantly trends in the other stations, with the Sig. 0.90 in Qurayate and 0.95 in both Al Hassa, Tabouk, Turayf and Yanbu. The Sen's slope values of (Tx) were ranging between 0.06˚C/year in Yanbu and 0.07˚C/year in Qurayate, indicate an increase of approximately 0.2˚C per decade. The increasing trends in temperature as found in this research are consistent with several previously published works in different geographical locations (Kabo-Bah et al., 2016; Nkrumah et al., 2014; Hasanean, 2001; Türkeş et al., 2002; Domonkos et al., 2003).

Table 9. The trends of temperatures for 1985-2023 obtained using Mann-Kendall test.

Time series		First year	Last Year	n	Test Z	Sig.	Q	Test S
Maximum temperature (˚C)	**Abha**	1985	2023	39	3.36	0.999	0.059	Increased trend
	Al Bahah	1985	2023	39	0.20	---	0.000	No trend
	Al Hassa	1985	2023	39	3.06	0.95	0.061	Increased trend
	Al Jouf	1985	2023	39	1.38	---	0.038	No trend
	Qurayate	1985	2023	39	2.27	0.90	0.065	Increased trend
	Rafha	1985	2023	39	1.47	---	0.039	No trend
	Riyadh	1985	2023	39	−0.90	---	0.000	No trend
	Tabouk	1985	2023	39	2.87	0.95	0.056	Increased trend
	Turayf	1985	2023	39	2.81	0.95	0.083	Increased trend
	Yanbu	1985	2023	39	2.77	0.95	0.061	Increased trend

Continued

Minimum temperature (˚C)	**Abha**	1985	2023	39	2.28	0.90	0.062	Increased trend
	Al Bahah	1985	2023	39	1.25	---	0.025	No trend
	Al Hassa	1985	2023	39	2.25	0.90	0.068	Increased trend
	Al Jouf	1985	2023	39	1.40	---	0.038	No trend
	Qurayate	1985	2023	39	0.29	---	0.000	No trend
	Rafha	1985	2023	39	0.66	---	0.009	No trend
	Riyadh	1985	2023	39	2.12	0.90	0.085	Increased trend
	Tabouk	1985	2023	39	1.22	---	0.006	No trend
	Turayf	1985	2023	39	-0.84	---	-0.011	No trend
	Yanbu	1985	2023	39	0.48	---	0.000	No trend

In contrary, all observed trends of minimum daily temperatures were not significant at All stations, except Abha, Al Hassa and Riyadh. In these stations, the minimum daily temperature had an increased significantly trends with the Sig. 0.90. Similarly, the Sen's slope value for the increasing trends were detected with 0.06˚C/year in Abha, 0.07˚C/year in Al Hassa and 0.09˚C/year in Riyadh, indicate an increase of approximately 0.6˚C, 0.7˚C and 0.9˚C per decade, respectively. There was an increase in (Tm) revealed in many previously studies (Almazroui, 2020; Al-Mutairi et al., 2023). The Mann-Kendall and Sen'sslope tests revealed no trends in the (Tx) in Al Bahah, Al Jouf, Rafha and Riyadh; and in the (Tm) in Al Bahah, Al Jouf, Qurayate, Rafha, Tabouk, Turayf and Yanbu.

3.2. Discussion

Regarding the temperature patterns, this study revealed a statistically significant increasing trend in the maximum daily temperature (Tx) in Abha, Al Hassa, Qurayate, Tabouk, Turayf and Yanbu, indicating an increase of approximately 0.59˚C, 0.61˚C, 0.65˚C, 0.56˚C, 0.83˚C and 0.61˚C per decade respectively. Similarly, the minimum daily temperature showed an increasing trends in only Abha, Al Hassa and Riyadh, indicating an increase of approximately 0.62˚C, 0.68˚C and 0.85˚C per decade, respectively. These findings are consistent with the trends observed in six studies across Saudi Arabia, showing a statistically significant increasing trend in minimum and maximum daily temperatures.

Reference (Al-Mutairi et al., 2023) shows the results of the MK tests suggesting the existence of a warming trend in temperatures over the regions of Saudi Arabia. The findings revealed the most significant warming trends for time series with a higher warming rate in the stations of the northeast region and the strongest warming trend in the central, northeastern, and southeastern parts of SA. Overall, it was found the highland stations in the western region have higher trend magnitudes in winter, while the northern stations have lower trend magnitudes. The occurrence of abrupt changes may be related to El Niño and La Niña (Vorhees, 2006).

In Reference (Almazroui, 2020) the different temperature indices were analyzed to determine the linear trends in temperature extremes over Saudi Arabia. The results suggest the existence of a warming trend in recent decades, the maximum and minimum temperatures are above normal in most years compared to previous decades. In the latest 20 years (2000-2019), a large increase in maximum (minimum) temperatures was observed in Feb-Mar (June-Aug) compared to the previous 20 years (1980-1999). Overall, the results indicate that warm extremes have increased during the recent two decades (2000-2019) over Saudi Arabia. Reference (Rehman & Al-Hadhrami, 2012) has been assessed the long-term change in temperature by Mann-Kendell rank statistics and linear trend analysis for over approximately last four decades stretching between years 1970 and 2006. Significant increase was observed in hot days per year and relatively smaller decrease in hot nights. Significant increase in summer time temperatures was confirmed by both linear regression analysis and M-K rank statistics. The monthly and annual mean maximum temperatures have increased more than the mean and mean minimum temperatures.

In the study of Reference (Tarawneh & Chowdhury, 2018), future trends of temperature and rainfall were assessed for several regions in Saudi Arabia. The linear and Mann-Kendall analyses showed an increase of temperature in all regions. Following trend analysis, the outputs of the NCAR Community Climate System Model were obtained for the assessment periods of 2025-2044, 2045-2064 and 2065-2084 were compared with the average values from the reference period (1986-2005). In all emission scenarios, temperature showed an increase from 1986 to 2005 in all regions. The increase of temperature are in the ranges of 0.8˚C - 1.6˚C, 0.9˚C - 2.7˚C and 0.7˚C - 4.1˚C during 2025-2044, 2045-2064 and 2065-2084 respectively.

The Reference (Odnoletkova & Patzek, 2021) observed similar warming trends during the study period of 1979-2019 with data obtained from the state-of-the-art ECMWFERA5 reanalysis of global climate. Rapid growth in warm days has resulted in an exponential increase of heat wave duration in most of the studied cities. Coastal locations are less affected by the rise of temperature and the temperature extremes. But these areas are strongly impacted by the elevation of heat index. The magnitude of changes over the Persian Gulf coast is generally higher than over the Red Sea.

The Reference (Al Dughairi, 2025) revealed that the climatic factors in the study region underwent considerable changes from 1978 to 2018. A rise in temperature, with the most pronounced alterations noted at Qaysumah station, was noticed. The results indicate a prevailing warming trend, especially in minimum temperatures and a decrease in relative humidity in Al Jawf, whereas Qaysumah observed an increase in humidity.

4. Conclusions

The values of CV of maximum temperatures decrease gradually from the north to the south of SA. The greater values of the CV of (Tx) happen at Qurayate and Turayf. In the Central area, Northern borders and Eastern Province the values of CV for (Tx) reach 0.42, 0.51 and 0.39, respectively. The lowest CV characterize Yanbu (Western coast) and Abha and Al Bahah (Assir) with 0.25, 0.35 and 0.34, respectively.

In the contrary, the CV values of (Tm) were smaller than those for (Tx) in all regions and were ranged from 0.28 at Tabouk to 0.36 at Turayf in Northern area, 0.33 at Rafha (Northern borders), 0.27 at both Riyadh (Central area)and Al Hassa (Eastern Province), 0.21 at Abha and 0.20 at Al Bahah (Assir) and 0.16 at Yanbu (Western coast).

From Pettit's test, the computed p-value of Maximum daily temperatures (Tx) is greater than the significant level (alph: 0.05) at the total of stations, except Turayf. The results of SNHT test also consistent with the results of Pettit's test. These two tests indicate the homogeneous data at all stations. The results of Buishand's test confirm the results of SNHT test with p-values ranged between 0.107 at Turayf and 0.913 at Tabouk.

In addition, from Pettit's test, the computed p-value of Minimum daily temperatures (Tm) are greater than the critical value (alph: 0.05) at the total of stations, indicating the homogeneous data in all stations. The results of Buishand's test are not different from the results of Pettit's test, with p-values greater than the critical value 0.05 at all stations, except Al Bahah, indicating the homogeneous data of daily minimum temperatures recorded from 1985 to 2023. In contrast to the results of SNHT test show the p-values greater than the critical value 0.05 at all stations, except Al Bahah, Rafha and Riyadh.

The frequency distribution of the main class of (Tx) differs from that of (Tm), with (10˚C - 20˚C) in Abha and (20˚C - 30˚C) in Al Bahah, Tabouk, Al Jouf, Al Hassa, Qurayate, Rafha and Turayf, (15˚C to 25˚C) in Yanbu and Riyadh,. However, the frequency distribution of the main class of (Tm) revealed that the main classes of (10˚C - 20˚C) in Abha and Qurayate, (15˚C - 25˚C) in Al Bahah, Tabouk, Yanbu, Al Jouf, Riyadh and Turayf, and (20˚C - 30˚C) in Al Hassa and Rafha.

The trends for the daily temperature were analyzed using the semi-averages method and T-student test. The results showed three increasing and non-significant trends and seven decreasing and non-significant trends of (Tx) at the degree of freedom 18.

The results of this test for the semi-averages of the minimum temperatures at the degree of freedom 18, also showed four decreasing and non-significant trends and three increasing and non-significant trends. Only, the trends in minimum temperatures were increasing and significant in the Abha, Al-Ahsa and Tabuk stations.

The Mann-Kendal test (Z), combined with Sen's slope estimator (Q) revealed an increased significant of (Tx) trends in only Abha, Al Hassa, Qurayate, Tabouk, Turayf and Yanbu. In contrary, all observed trends of minimum daily temperatures were not significant at All stations, except Abha, Al Hassa and Riyadh.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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