

Analysis of Air Temperature Trends as a Climate Change Indicator for Alexandria (Egypt)

By Tarek M. El-Geziry*

This work provides the results of the analyzed long-term trends for three air temperature categories, namely: average (T_{avg}), maximum (T_{max}) and minimum (T_{min}) on monthly, annual and seasonal bases for Alexandria. The aim was to examine possible climate changes in this famous City based on the results obtained from the analyzed trends. The study was based on examining (1) linear regression approaches, (2) trend magnitudes, (3) Mann-Kendall trend test and (4) extreme air temperature events. The air temperature data from Alexandria International Airport station were used over a period of 65 years (1957-2021). For all analyzed time series, the results showed statistically significant positive trends. The exception was for the monthly mean T_{max} during January, February and December (negative trends), and March (No trend). The H_1 hypothesis prevails for the three temperature categories, on different basis. Over the period of investigation, both the annual mean T_{avg} and T_{min} rose at a rate of $+0.02\text{ }^{\circ}\text{C/yr}$, while annual mean T_{max} rose at a rate of $+0.008\text{ }^{\circ}\text{C/yr}$. In winter, the annual mean T_{avg} and T_{min} had increasing trends at a rate of $+0.02\text{ }^{\circ}\text{C/yr}$. The winter T_{max} had a feeble increasing trend (almost constant), at a rate of only $+0.0003\text{ }^{\circ}\text{C/yr}$. In summer, the three air temperature categories increased at a rate of $+0.02\text{ }^{\circ}\text{C/yr}$, each. Extreme air temperature times were specified in this study on all bases for the three temperature categories. The findings of this study are thought to be a reliable indicator of the presence of climate change in Alexandria.

Keywords: Alexandria, air temperature, climate change, trend analysis, extremes

Introduction

The term ‘climate change’ refers to the alteration in the conditions of the climate brought on by long-lasting changes to one of its characteristics, generally lasting decades or longer (Masson et al. 2021).

Latitude, altitude, the tilt of the Earth's axis, temperature differences between land and sea, and topography all have a significant impact on the Earth's climate (Thapa et al. 2021). A growing body of scientific evidence suggests that the atmosphere of the earth has altered over time, signaling that the globe is warming (Masson et al. 2021; Thapa et al. 2021). Various anthropogenic activities that generate pollutants are mostly to blame for this change, with natural causes playing a smaller role (Jonathan and Raju 2017). Many indicators of climate change are evident around the world. This comprises but not limited to higher air temperatures, more drier areas, wilder weather with significant changes in rainfall

*Professor and Head of Laboratory of Physical Oceanography, Division of Marine Environment, National Institute of Oceanography and Fisheries (NIOF), Egypt.

patterns, increased ocean acidity, warmer seas, and quicker rates of sea-level rise (El-Geziry 2021; Tonbol et al. 2018).

The most visible evidence of climate change is the significant rapid increase in air temperature observed in recent decades around the world (Arghius et al. 2020).

According to the Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC 2013), global surface temperature data calculated using linear trend showed a 0.85 °C warming from 1880 to 2012. However, the spatiotemporal distribution of the increase in global air temperature is not uniform on Earth. The rise in air temperature varies by region, with the northern hemisphere experiencing a greater increase in air temperature (Bačević et al. 2020). Rising air temperatures may have various effects on various aspects of human life, particularly on human settlements, agricultural products, energy consumption, environmental and social processes and so on (Bonacci et al. 2021; Piticar and Ristoiu 2014). Temperature variations are significant for understanding the overall climatic structure (Atilgan et al. 2017) as well as determining the best planning adaptation techniques in a given area (Marin et al. 2014).

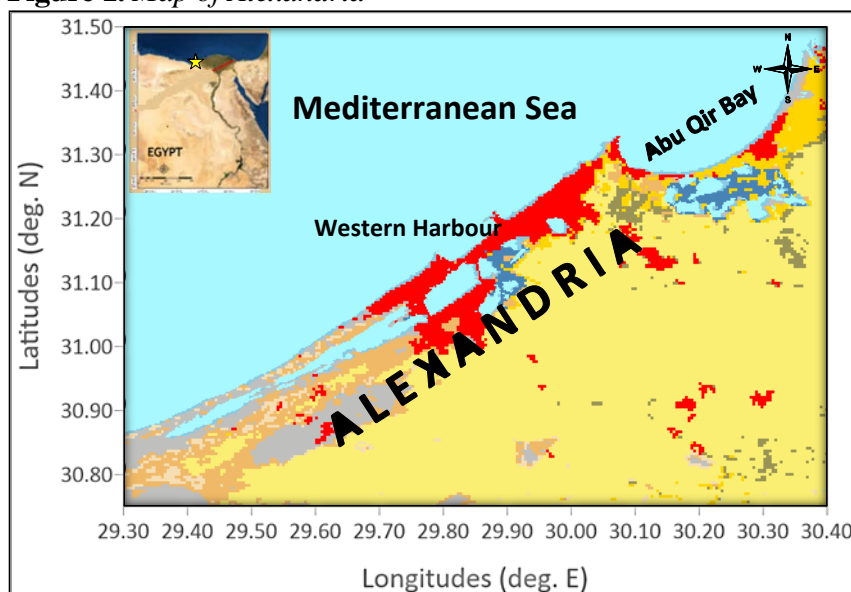
Several studies have looked at the temporal variability of temperature at various temporal and regional scales over the previous few decades, confirming a significant warming in the Middle East and North Africa (Eid et al. 2019; El Kenawy et al. 2015; 2009; Fontaine et al. 2013; Paeth et al. 2009). The air temperature trends and data from eight meteorological stations in the eastern Mediterranean basin were analyzed by Hasanean (2001), who found strong positive trends in Malta and Tripoli, and negative trends in Amman. Türkeş et al. (2002) examined mean, maximum, and minimum air temperature data in Turkey from 1929 to 1999. Their findings revealed patterns of variations in the long-term trends with time and locations, transition points, and crucial warming and cooling cycles. Maiyza et al. (2011) examined the changing behaviour of the mean monthly air temperature anomalies within the Levantine Basin and revealed a general decrease of 0.01 °C/yr from 1958 to 1990. They also came to the conclusion that the 70-year cycle has been one of the most important contributors to climate change in the southeast Mediterranean region after examining variations in air temperature, hydrography, and the phenomena of River Nile droughts. The Southern Levantine Basin's mean annual and monthly air temperature fluctuations and trends between 2007 and 2016 were examined by Tonbol et al. (2018). The hottest year in the area, according to their research, was 2010, while the coldest was 2011. Additionally, a general trend of rising mean monthly air temperature anomaly was revealed. Ibrahim et al. (2021) concluded that the frequency trend of marine heatwaves (MHW) in the eastern Mediterranean has increased by 1.2 events/decade between 1982 and 2020.

Egypt is regarded as one of the most susceptible countries to the long-term effects of climate change, which are exacerbated by an increase in the frequency and severity of extreme weather events. Egypt's water shortage is anticipated to worsen due to global warming, which will also spread to the semi-arid area and increase the strength and frequency of maritime storms (El-Geziry 2021). According to Zaki and Swelam (2017), Egypt has experienced regional changes in

floods, droughts, and wildfires, as well as more intense and prolonged heat waves and less frequent and intense cold waves. A succession of heat waves have devastated the entirety of Egypt, with the heat waves of 2010 and 2015 killing over a hundred people who were exposed to extremely high temperatures that persisted for days, not just during the day but also at night (Mostafa et al. 2019). According to the results of Eid et al. (2019), seasonal and annual values of temperature exhibited a significant trend of increase over Egypt through the period 1960-2016.

Alexandria of Egypt is an ancient and important historical metropolis and cosmopolitan city on the Mediterranean coast. The City extends between latitudes 30.70° – 31.34° N and longitudes 29.40° – 30.10° E (Figure 1), and hosts 40% of Egypt's industrial activities (Abdel-Shafy et al. 2010; Abou-Mahmoud 2021). The coastline of Alexandria extends for about 75 km from Al-Hammam (west) to Abu Qir (east) (Abou-Mahmoud 2021). The City, which is one of the UNESCO world heritage sites, faces the risks from climate change, seen in so many phenomena: sea-level rise associated with flooding and erosion, increased air temperature, altered rainfall patterns, etc.

Figure 1. Map of Alexandria



Source: Author by using Surfer16® Software.

According to Hendy (2018) and Said et al. (2012a), Alexandria has only two seasons: a hot summer from April to September and a mild winter from October to March. The differences between seasons are primarily due to variations in daytime temperature and wind patterns. The average annual air temperature ranges from 14.0°C in winter to 30.0°C in summer (Hendy 2018; Mohamed and Beltagy 2009). Said et al. (2012b) determined an increasing rate of about $0.6^{\circ}\text{C}/\text{decade}$ in the mean annual air temperature in Alexandria over the period from 1979 to 2011. The City had three heatwaves in 1999, with temperatures exceeding historical averages on five days in April (> 26 – 30°C), seven occasions in August ($> 30^{\circ}\text{C}$), and five occasions in November ($> 26^{\circ}\text{C}$) (Said et al. 2012a). Tonbol et al. (2018),

on the other hand, examined the air temperature behavior at Alexandria from 2007 to 2016 and found that Alexandria had a severe cold wave in winter 2010, when the observed air temperature dropped from 22.2 to 8.8 °C, over a 5-day period from December 11 to 15, 2010. El-Geziry (2021) calculated a mean annual air temperature of 20.8 °C for Alexandria over the period 1980-2019 and concluded a general trend of increase of 0.04 °C/yr (0.4 °C/decade) over the same period. He also showed that this rate varied from cold to warm seasons, being 0.08 °C/yr and 0.06 °C/yr, respectively.

The examination of extended records of meteorological data yields useful information, which aids in achieving a quantitative understanding of these two interrelated goals (Mohamed and Beltagy 2009). The study of temperature fluctuations is an indicator of climate change in the important city of Alexandria, with the goal of assisting decision-makers, interested in human services and development, in presenting projects that limit the problems with it. Therefore, the primary goal of this research is to investigate temperature variability, detect significant trends, and assess its increase over the last 65 years (1957-2021).

Data and Methods of Analysis

This study used data for average (T_{avg}), maximum (T_{max}) and minimum (T_{min}) air temperatures, on a monthly, annual and seasonal basis, recorded at the Alexandria International Airport Meteorological Station No. 62318 (31.22° N; 29.94° E) at 2 m below the mean sea level. The data covered 65 years of records from January 1957 to December 2021, with 0% missing data. The data was downloaded from the website: <https://en.tutiempo.net/climate/ws-623180.html>.

The obtained data sets were subjected to four types of analysis, as follows:

1. Linear Regression

Linear regression is a parametric criterion for determining the relationship between two or more dependent and independent variables that are linked by a causal relationship. With a 95% confidence interval, this test determines whether a linear relationship and trend exist between variables (Atilgan et al. 2017; Singh et al. 2015). Equation 1 depicts the linear regression equation:

$$Y = a + b X \quad (1)$$

Where Y is the dependent variable (here is the air temperature), a is the slope coefficient, b is the interception and X is the independent variable (here is the time).

The linear regression test's significance is determined using a 95% confidence interval and a Student t-test (significance levels such as 5%, 1%) (Atilgan et al. 2017; Sneyers 1990).

2. Trend Magnitude

The slope size determines the value of the air temperature trend. There are three scenarios to consider: The trend is positive if the slope size is greater than zero; no trend if the slope size is equal to zero; and negative if the slope size is less than zero. The trend magnitude is calculated using the trend equation (Bačević et al. 2020; Gavrilov et al. 2015).

$$\Delta y = y(1957) - y(2021) \quad (2)$$

Where Δy is the trend magnitude in degrees Celsius, $y(1957)$ is the air temperature's value at the start of the period, and $y(2021)$ is the air temperature's value at the conclusion of the period. There are three different options when it comes to trend magnitude: a) the trend is negative when Δy is greater than zero; b) when Δy is less than zero, the trend is positive; and c) when Δy is equal to zero, no trend exists.

3. Mann-Kendall Test

The Mann–Kendall (MK) test is a non-parametric test used to identify trends in time series data. It is one of the best methods for analysis that determines statistical significance through hypothesis testing. The MK trend test is used in long-term temporal data to detect statistically significant decreasing or increasing trends. This test is based on two hypotheses: the null (H_0) hypothesis, which assumes that there is no trend (the data are independent and randomly ordered), and the alternate (H_1) hypothesis, which elucidates significant rising or declining trends in data. The non-parametric MK test yields more accurate and reliable results than parametric tests (Kale 2017). The statistic formulas of MK test are given in the following Equations:

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^n \text{sgn}(x_k - x_i) \quad (3)$$

Where the time series x_i is from $i = 1, 2, \dots, n-1$, x_k is from $k = i + 1, \dots, n$ and n here is the number of months/years.

$$\text{sgn}(x_k - x_i) = \begin{cases} +1 & \text{if } (x_k - x_i) > 0 \\ 0 & \text{if } (x_k - x_i) = 0 \\ -1 & \text{if } (x_k - x_i) < 0 \end{cases} \quad (4)$$

$$\text{Var}(S) = \frac{1}{18} [n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5)] \quad (5)$$

Where t_p is the number of ties for the p^{th} value, and q is the number of tied values. Z_c is given as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \quad (6)$$

Where Z_c is the test statistic.

On the basis of a 5% significance threshold, if p-value is $\leq \alpha = 0.05$, the H_1 hypothesis is accepted, indicating a trend in the data. If p-value is $\geq \alpha = 0.05$, the absence of a trend in the data is shown, and H_0 is accepted (Arghius et al. 2020; Atilgan et al. 2017; Bačević et al. 2020; Kale 2017; Shadmani et al. 2012; Singh et al. 2015; Subarna 2017).

4. Extreme Air Temperature

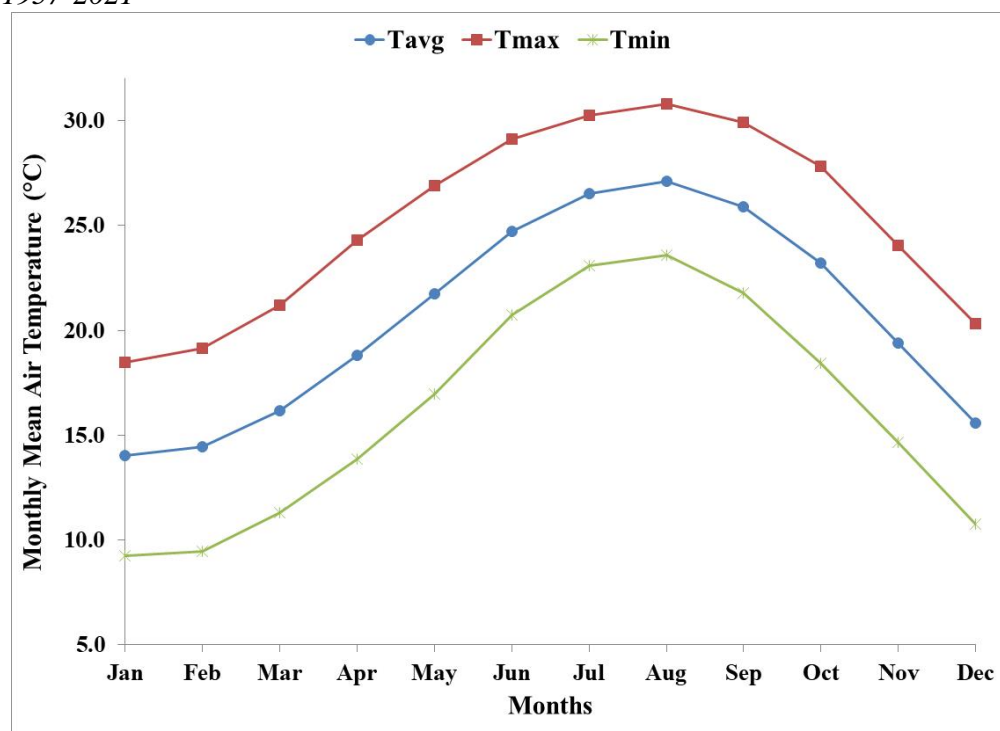
According to (ElBessa et al. 2021; Sridhar and Bhole 2015), an extreme air temperature event is defined as the event (record) calculated as $\text{Mean} \pm 2 \times \text{SD}$, where SD is the standard deviation.

Results

Linear Regressions

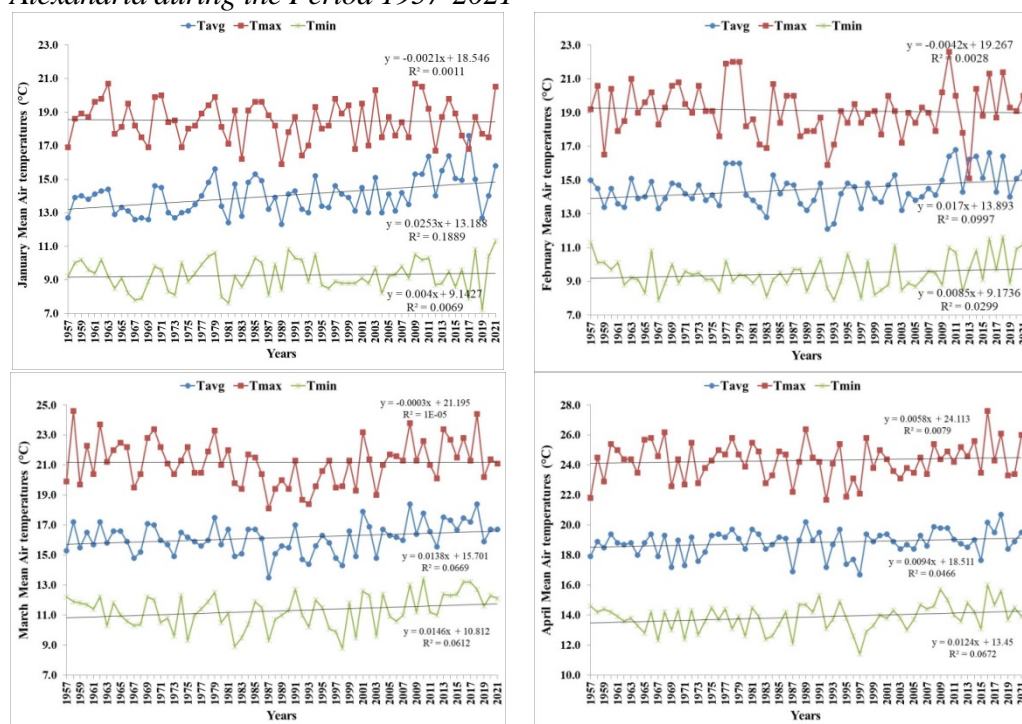
The monthly mean air temperatures for the three recorded parameters (T_{avg} , T_{max} and T_{min}) are shown in Figure 2. The mean annual T_{avg} was 20.6 °C, while that of T_{max} and T_{min} was 25.2 °C and 16.2 °C, respectively. January was the month of lowest monthly means with values of 14.0 °C, 18.5 °C, 9.3 °C for T_{avg} , T_{max} and T_{min} , respectively. On the other hand, August was the month with the highest monthly means with values of 27.1 °C, 30.8 °C, 23.6 °C for T_{avg} , T_{max} and T_{min} , respectively. Figure 3 depicts the trends of the monthly mean air temperatures (T_{avg} , T_{max} and T_{min}) for Alexandria over the period 1957-2021, using the parametric linear regression approach. As shown, the monthly T_{avg} had a general trend of increase for all months, with different rates over the period of interest. The lowest rate occurred in April (+0.009 °C/yr), while the highest occurred in September (+0.029 °C/yr). The monthly T_{max} behavior varied over the period of investigation with three different trends: decreasing trend occurred in three successive months (December-February) with the lowest trend of -0.004°C/yr in February and December and a maximum of -0.002 °C/yr in January. March was a month of almost no change in the trend of T_{max} over the period of interest, with a trend as low as -0.0003 °C/yr. The positive trends of the monthly T_{max} extended from April to November, with the lowest rate of +0.005 °C/yr in April and November, and the highest of +0.024 °C/yr in September. The monthly T_{min} followed the same trend of increase detected for the monthly T_{avg} , but with different rates over the period of interest. The lowest rate was in January (+0.004°C/yr), while the highest was in October (+0.0036 °C/yr).

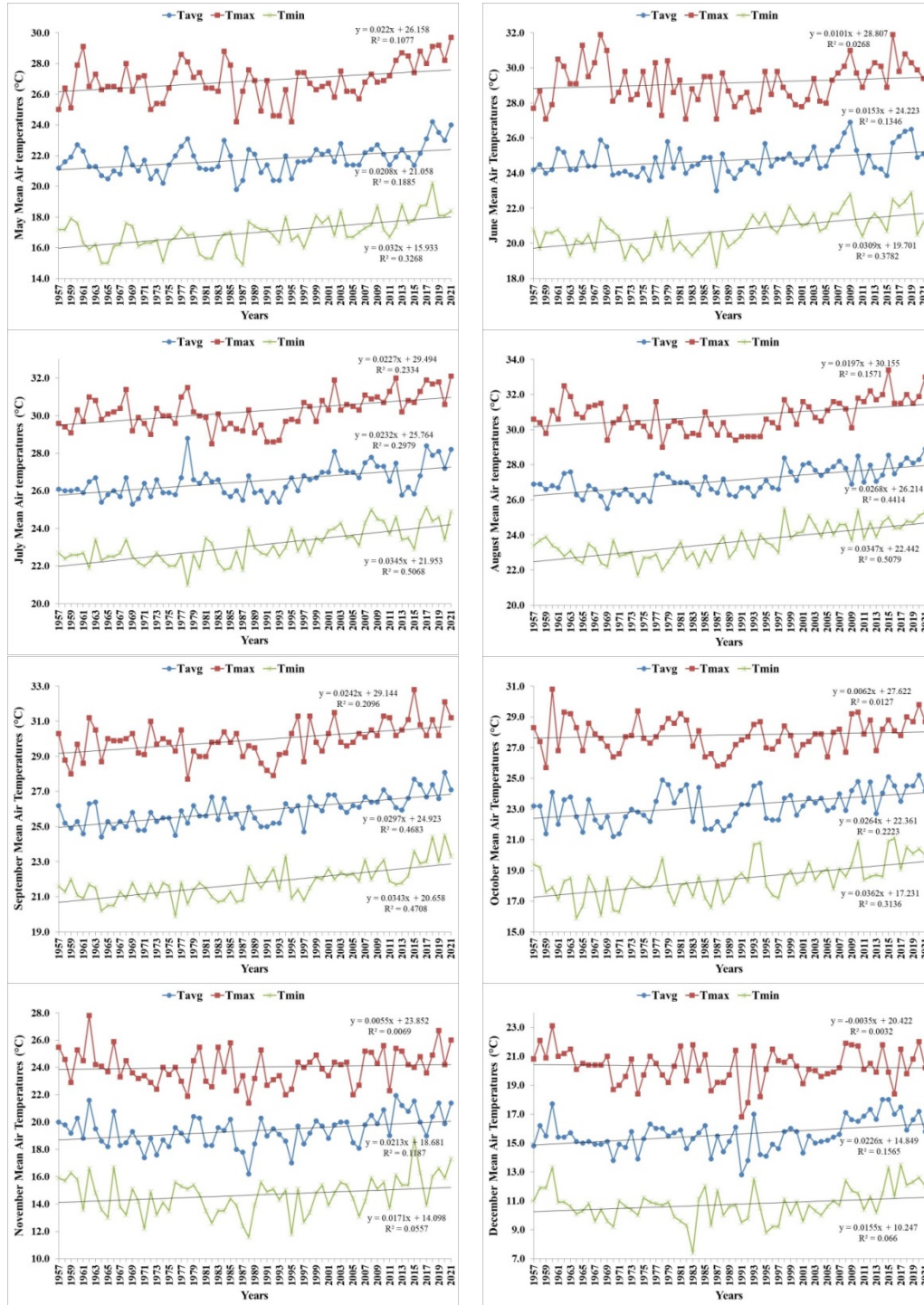
Figure 2. Monthly Mean Air Temperatures over Alexandria during the Period 1957-2021



Source: Author.

Figure 3. Linear Regression Trends of the Monthly Mean Air Temperatures over Alexandria during the Period 1957-2021



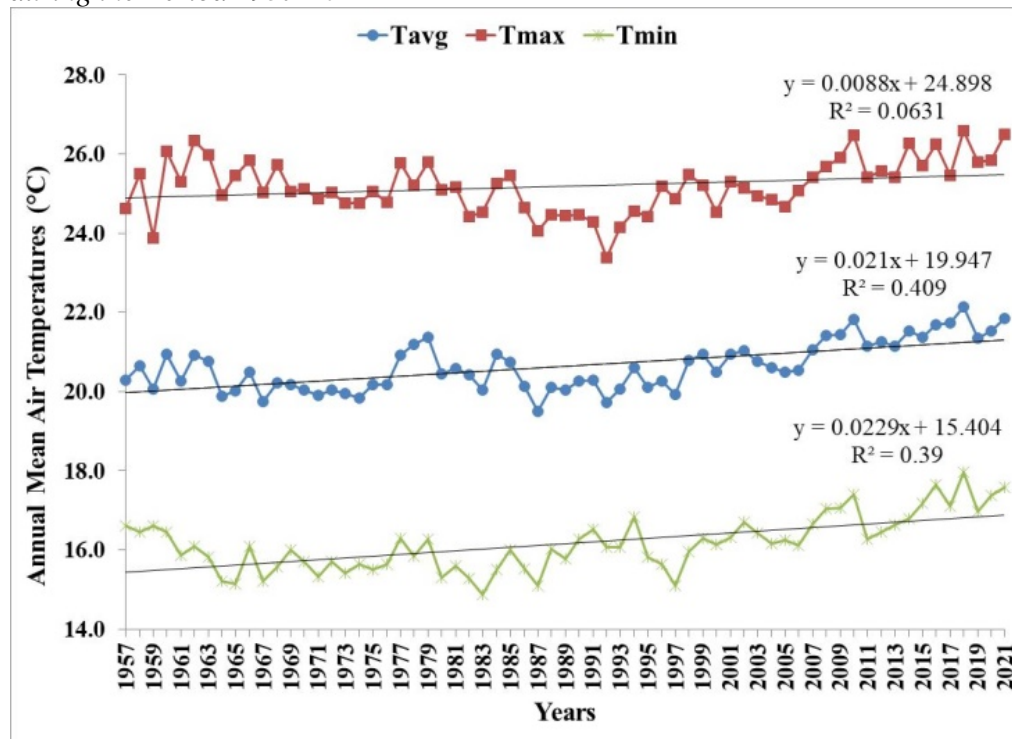


Source: Author.

The annual T_{avg} varied between 19.5 °C in 1987 and 22.1 °C in 2018, with an overall mean of 20.6 °C, over the period 1957-2021. The annual T_{avg} variations revealed an increasing trend over the period of investigation, with a rate of +0.02°C/yr. The annual T_{max} fluctuated between 23.4 °C in 1992 and 26.6 °C in 2018, with a T_{max} mean value of 25.2 °C, over the period of examination. The T_{max}

annual variability showed an increasing trend with a rate of $+0.008\text{ }^{\circ}\text{C/yr}$ over the period 1957-2021. Lastly, the annual T_{\min} ranged between $14.9\text{ }^{\circ}\text{C}$ in 1983 and $18.0\text{ }^{\circ}\text{C}$ in 2018, with an overall mean of $16.2\text{ }^{\circ}\text{C}$, over the study period. The annual T_{\min} trend of variation revealed an increasing trend over the period 1957-2021 with a rate of $+0.02\text{ }^{\circ}\text{C/yr}$. The mean annual variations of the three air temperatures over Alexandria are depicted in Figure 4.

Figure 4. Annual Mean Air Temperatures and Their Trends over Alexandria during the Period 1957-2021



Source: Author.

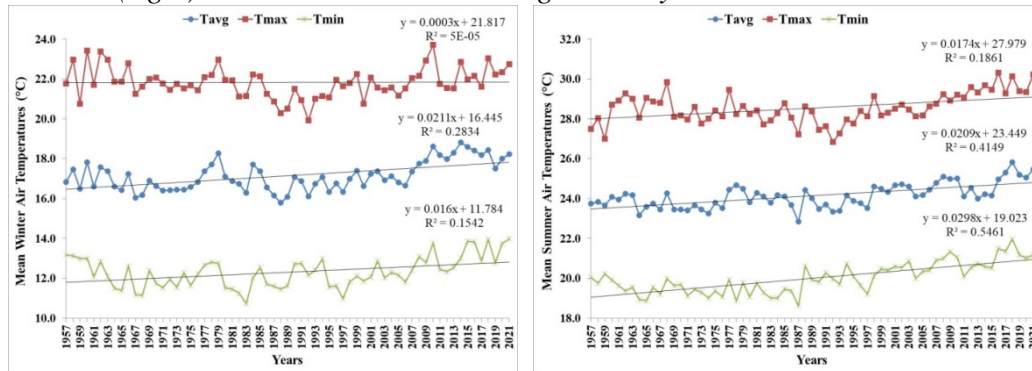
Alexandria exhibits two seasons over the year: a mild winter from October to March and a hot summer from April to September. The three examined air temperatures fluctuate and vary from one season to the second. In winter, the annual mean T_{avg} fluctuated over the period 1957-2021 between $15.8\text{ }^{\circ}\text{C}$ in 1988 and $18.8\text{ }^{\circ}\text{C}$ in 2014, with an overall mean of $17.1\text{ }^{\circ}\text{C}$. The trend of annual mean winter T_{avg} fluctuations reflected an increasing trend with a rate of $0.02\text{ }^{\circ}\text{C/yr}$. The annual mean winter T_{max} ranged between $19.9\text{ }^{\circ}\text{C}$ in 1992 and $23.7\text{ }^{\circ}\text{C}$ in 2010, with a winter mean of $21.8\text{ }^{\circ}\text{C}$, over the investigated period. The winter T_{max} had a feeble increasing trend (almost constant) over the period 1957-2021, with a rate of $+0.0003\text{ }^{\circ}\text{C/yr}$. Lastly, the annual mean winter T_{min} varied between $10.7\text{ }^{\circ}\text{C}$ in 1983 and $14.0\text{ }^{\circ}\text{C}$ in 2018, with an overall average of $12.3\text{ }^{\circ}\text{C}$, over the period of interest. The increasing trend of the annual mean T_{min} in winter occurred with a rate of $+0.02\text{ }^{\circ}\text{C/yr}$.

In summer, the annual mean T_{avg} varied between $22.9\text{ }^{\circ}\text{C}$ in 1987 and $25.8\text{ }^{\circ}\text{C}$ in 2018, with an overall mean of $24.1\text{ }^{\circ}\text{C}$, over the period 1957-2021. The warm

T_{avg} showed an increasing trend with a rate of $+0.02\text{ }^{\circ}\text{C/yr}$. The hot annual mean T_{max} fluctuated between $26.8\text{ }^{\circ}\text{C}$ in 1992 and $30.3\text{ }^{\circ}\text{C}$ in 2016, with a mean of $28.5\text{ }^{\circ}\text{C}$, over the study period. The warm T_{max} had an increasing trend of $+0.02\text{ }^{\circ}\text{C/yr}$. Lastly, the annual mean T_{min} in summer varied between $18.6\text{ }^{\circ}\text{C}$ in 1987 and $22.0\text{ }^{\circ}\text{C}$ in 2018, with a mean of $20.0\text{ }^{\circ}\text{C}$, over the study period. The annual mean T_{min} in summer showed an increasing trend with a rate of $+0.02\text{ }^{\circ}\text{C/yr}$.

The seasonal fluctuations in the three air temperature parameters and their trends of variation are shown in Figure 5.

Figure 5. Seasonal Mean Air Temperatures over Alexandria in Winter (left) and Summer (right) and the Their Trends during the Study Period



Source: Author.

Trend Magnitudes

Using Equation (2), the monthly mean trend magnitudes for the three air temperatures in this study were calculated. The results are shown in Table 1. The calculated magnitudes are consistent with the concluded trends of monthly mean variations. This can be detected from the positive magnitudes for the T_{max} in January, February and December, the zero value for T_{max} in March and the negative magnitudes for the 12 months for T_{avg} and T_{min} . From these magnitudes, one can conclude the larger alterations in the behavior of change for the T_{min} than for both T_{avg} and T_{max} . Table 2 shows the annual mean trend magnitudes of the three examined air temperatures over Alexandria during the period 1957-2021. The obtained negative magnitudes confirm the positive trends of variations concluded for the three air temperature parameters over Alexandria during the study period. Table 3 shows the seasonal mean trend magnitudes of the three examined air temperatures over Alexandria during the period 1957-2021. The seasonal mean T_{avg} had the same magnitude of $-1.4\text{ }^{\circ}\text{C}$ in both winter and summer, reflecting the positive increasing behavior over the study period. The mean T_{max} did not change during winter, having $0.0\text{ }^{\circ}\text{C}$ magnitude. The negative magnitudes of the seasonal mean T_{min} during both winter and summer revealed its seasonal positive trend of increase.

Table 1. Monthly Mean Trend Magnitudes of the Different Air Temperatures over Alexandria during the Period 1957-2021

	T_{avg}		T_{max}		T_{min}	
	Trend Equation	ΔT_{avg}	Trend Equation	ΔT_{max}	Trend Equation	ΔT_{min}
Jan	$y = 0.0253x + 13.188$	-1.6	$y = -0.0021x + 18.546$	0.1	$y = 0.004x + 9.1427$	-0.2
Feb	$y = 0.017x + 13.893$	-1.1	$y = -0.0042x + 19.267$	0.2	$y = 0.0085x + 9.1736$	-0.6
Mar	$y = 0.0138x + 15.701$	-0.9	$y = -0.0003x + 21.195$	0.0	$y = 0.0146x + 10.812$	-0.9
Apr	$y = 0.0094x + 18.511$	-0.6	$y = 0.0058x + 24.113$	-0.3	$y = 0.0124x + 13.45$	-0.8
May	$y = 0.0208x + 21.058$	-1.3	$y = 0.022x + 26.158$	-1.4	$y = 0.032x + 15.933$	-2.0
Jun	$y = 0.0153x + 24.223$	-0.9	$y = 0.0101x + 28.807$	-0.7	$y = 0.0309x + 19.701$	-1.9
Jul	$y = 0.0232x + 25.764$	-1.5	$y = 0.0227x + 29.494$	-1.5	$y = 0.0345x + 21.953$	-2.2
Aug	$y = 0.0268x + 26.214$	-1.7	$y = 0.0197x + 30.155$	-1.3	$y = 0.0347x + 22.442$	-2.3
Sep	$y = 0.0297x + 24.923$	-1.9	$y = 0.0242x + 29.144$	-1.6	$y = 0.0343x + 20.658$	-2.2
Oct	$y = 0.0264x + 22.361$	-1.6	$y = 0.0062x + 27.622$	-0.4	$y = 0.0362x + 17.231$	-2.3
Nov	$y = 0.0213x + 18.681$	-1.3	$y = 0.0055x + 23.852$	-0.4	$y = 0.0171x + 14.098$	-1.0
Dec	$y = 0.0226x + 14.849$	-1.4	$y = -0.0035x + 20.422$	0.3	$y = 0.0155x + 10.247$	-1.0

Source: Author.

Table 2. Annual Mean Trend Magnitudes of the Different Air Temperatures over Alexandria during the Period 1957-2021

	Trend Equation	ΔT (°C)
Annual Mean T_{avg}	$y = 0.021x + 19.947$	-1.4
Annual Mean T_{max}	$y = 0.0088x + 24.898$	-0.6
Annual Mean T_{min}	$y = 0.0229x + 15.404$	-1.5

Source: Author.

Table 3. Seasonal Mean Trend Magnitudes of the Different Air Temperatures over Alexandria during the Period 1957-2021

	T_{avg}		T_{max}		T_{min}	
	Trend Equation	ΔT_{avg}	Trend Equation	ΔT_{max}	Trend Equation	ΔT_{min}
Winter	$y = 0.0211x + 16.445$	-1.4	$y = 0.0003x + 21.817$	0.0	$y = 0.016x + 11.784$	-1.0
Summer	$y = 0.0209x + 23.449$	-1.4	$y = 0.0174x + 27.979$	-1.1	$y = 0.0298x + 19.023$	-1.9

Source: Author.

Mann-Kendall Non-Parametric Test

The results of the MK test for the monthly mean trend identification at a significance level of 0.05 are given in Table 4. As shown, T_{avg} and T_{min} showed an increasing trend over the entire period of investigation. However, T_{max} showed a mixture of increasing, decreasing and null trends. These results confirm those obtained using the linear regression approach and the calculated trend magnitudes.

Table 4. The MK Test Results for Air Temperatures on a Monthly Mean Basis

	T_{avg}			T_{max}			T_{min}		
	S	Z	Trend	S	Z	Trend	S	Z	Trend
Jan	308	2.52	+	171	-2.52	-	296	2.42	+
Feb	314	2.56	+	174	-2.56	-	301	2.45	+
Mar	303	2.48	+	131	1.93	No	291	2.38	+
Apr	266	2.0	+	168	2.48	+	255	1.97	+
May	338	2.76	+	187	2.76	+	325	2.65	+
Jun	238	2.0	+	132	1.98	+	228	1.98	+
Jul	307	2.52	+	151	2.22	+	295	2.42	+
Aug	327	2.67	+	181	2.67	+	314	2.56	+
Sep	303	2.48	+	168	2.48	+	291	2.38	+
Oct	309	2.52	+	171	2.52	+	182	1.98	+
Nov	190	1.98	+	165	2.43	+	297	2.09	+
Dec	287	2.12	+	159	-2.34	-	276	2.03	+

Source: Author.

The MK test was applied to examine the annual mean trends of air temperatures over the period of investigation. Significant trends were increasing for the three examined parameters (Table 5). As shown, trends are statistically significant at 99% significant level for both T_{avg} and T_{min} , while this drops to a significant level of 95% for T_{max} .

Table 5. The MK Test Results for Air Temperatures on an Annual Mean Basis

	T_{avg}			T_{max}			T_{min}		
	S	Z	Trend	S	Z	Trend	S	Z	Trend
Annual Mean	938	5.3	+	361	2.03	+	905	5.11	+

Source: Author.

The results of the MK test for the two seasons, mild winter and warm summer, affecting Alexandria are shown in Table 6. The significant level of both T_{avg} and T_{min} was 99%, while that of T_{max} was 95%.

Table 6. The MK Test Results for Air Temperatures on a Seasonal Mean Basis

	T_{avg}			T_{max}			T_{min}		
	S	Z	Trend	S	Z	Trend	S	Z	Trend
Winter	260	3.82	+	101	1.46	No	251	3.68	+
Summer	363	5.34	+	140	2.04	+	350	5.14	+

Source: Author.

Extreme Air Temperatures

The statistics of the monthly mean air temperature to examine the monthly extreme values are shown in Table 7. The entire set of mean monthly T_{avg} showed extreme mean high air temperature (mean+2*SD) except for October. Also, monthly mean T_{avg} associated with extreme low air temperature (mean-2*SD) appeared all over the monthly set except for January, July, September and October. The extreme high monthly mean T_{max} appeared for the entire monthly set

but for January and the extreme low monthly mean T_{\max} existed for the entire monthly set but for the three successive months: June, July and August. On the other hand, the extreme high monthly mean T_{\min} occurred in the entire monthly set but in March, and the extreme low monthly mean T_{\min} did not appear in February, May and September.

Table 7. Statistics of the Monthly Mean T_{avg} , T_{max} and T_{min} in Alexandria during the Period 1957-2021

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly T_{avg} (°C)	14.0	14.5	16.2	18.8	21.7	24.7	26.5	27.1	25.9	23.2	19.4	15.6
SD (°C)	1.1	1.0	1.0	0.8	0.9	0.8	0.8	0.8	0.8	1.1	1.2	1.1
Extreme High T_{avg} (°C)	16.2	16.5	18.2	20.5	23.5	26.3	28.1	28.6	27.5	25.3	21.7	17.7
Extreme Low T_{avg} (°C)	11.8	12.4	14.2	17.2	19.9	23.2	24.9	25.6	24.3	21.1	17.1	13.5
Mean Monthly T_{max} (°C)	18.5	19.1	21.2	24.3	26.9	29.1	30.2	30.8	29.9	27.8	24.0	20.3
SD (°C)	1.2	1.5	1.5	1.2	1.3	1.2	0.9	0.9	1.0	1.0	1.2	1.2
Extreme High T_{max} (°C)	20.8	22.1	24.1	26.7	29.4	31.5	32.0	32.7	31.9	29.9	26.5	22.6
Extreme Low T_{max} (°C)	16.1	16.2	18.3	21.9	24.4	26.8	28.5	28.9	28.0	25.7	21.6	18.0
Mean Monthly T_{min} (°C)	9.3	9.5	11.3	13.9	17.0	20.7	23.1	23.6	21.8	18.4	14.7	10.8
SD (°C)	0.9	0.9	1.1	0.9	1.1	0.9	0.9	0.9	0.9	1.2	1.4	1.1
Extreme High T_{min} (°C)	11.1	11.3	13.5	15.7	19.1	22.6	24.9	25.4	23.7	20.8	17.4	13.0
Extreme Low T_{min} (°C)	7.5	7.6	9.1	12.1	14.9	18.8	21.3	21.8	19.9	16.0	11.9	8.5

Source: Author.

The extreme annual mean temperature is calculated as $20.6 \pm 2 \times 0.6$. Only 2 years, 2018 (22.1 °C) and 2021 (21.9 °C), out of 65 recorded extreme high annual mean T_{avg} in Alexandria from 1957 to 2021. No extremely low annual mean T_{avg} was recorded over the entire period of investigation. On the other, the extreme annual mean T_{max} is derived as $25.2 \pm 2 \times 0.7$. 2018 (26.6 °C) was the only year to record extremely high annual mean T_{max} , and 1992 (23.4 °C) was the only year to record extremely low annual mean T_{max} . The extreme high annual mean T_{min} was recorded in 3 years: 2016 (17.7 °C), 2018 (18.0 °C) and 2021 (17.6 °C), with no extreme low annual mean T_{min} detected over the whole period of interest. This T_{min} extremes were derived as $16.2 \pm 2 \times 0.7$.

The extreme seasonal mean air temperatures in the two seasons affecting Alexandria are associated with associated the equations $17.1 \pm 2 \times 0.7$ (winter) and $24.1 \pm 2 \times 0.6$ (summer) for T_{avg} , $21.8 \pm 2 \times 0.7$ (winter) and $28.6 \pm 2 \times 0.8$ (summer) for T_{max} , and $12.3 \pm 2 \times 0.8$ (winter) and $20.0 \pm 2 \times 0.8$ (summer) for T_{min} . Results revealed no extreme low T_{avg} winter temperatures during the study period. However, 3 years had extremely high T_{avg} : 2010 (18.6 °C), 2014 (18.8 °C) and 2015 (18.6 °C). Two extremely hot T_{avg} summer years were detected: 2018 (25.8 °C) and 2021 (25.5 °C), and one extremely low of 22.8 °C (1987). The winter high extreme T_{max} was detected in 3 years: 1960 (23.4 °C), 1962 (23.4 °C) and 2010 (23.7 °C), while the summer had only one extreme cold year with 19.9 °C in 1992. 2015 and 2021 were the two years of the extremely high T_{min} in Alexandria over the period

1957-2021, of 13.8 °C and 14.0 °C, respectively. Only 1983, with as low as 10.7 °C record, was detected as extremely low summer T_{\min} over the period of interest.

Discussion

It is critical to investigate the effects of climate change and to consider the outcomes of various climate change projects. Temperature variation is one of the most essential and crucial metrics of global climate change. Most climate models predict a rise in temperature by the end of the twenty-first century (García-Ruiz et al. 2011). It has been reported that rising temperatures may be linked to global warming (Chen and Xu 2005).

It is worth mentioning that this study is the first to examine the long-term behavior of T_{\max} and T_{\min} air temperatures in Alexandria in details. Therefore, there is no base study to compare the present findings of these two parameters. However, many previous studies have examined the variations in T_{avg} , and the present findings will be thoroughly compared and discussed considering results from these previous research.

In this study, the monthly pattern of air temperature change in Alexandria was demonstrated, with January having the lowest monthly means of 14.0 °C (T_{avg}), 18.5 °C (T_{\max}) and 9.3 °C (T_{\min}) and August having the highest of 27.1 °C (T_{avg}), 30.8 °C (T_{\max}) and 23.6 °C (T_{\min}). For T_{avg} , these findings are consistent with the findings of Hamed (1983) who declared January (13.7 °C) and August (26.1 °C) as months of highest and lowest monthly means over the period 1951-1980. Also, Mohamed and Beltagy (2009) showed the lowest monthly mean of 14.1 °C in January and the highest of 26.5 °C in August over the period 1958-2008. Results of Eid et al. (2019) revealed that January is the month with the lowest monthly mean (13.0 °C) and August of the highest (26.9 °C) over the period 1960-2016.

On a mean annual basis, this study revealed annual mean values of 20.6 °C, 25.2 °C, and 16.2 °C for T_{avg} , T_{\max} and T_{\min} , respectively. This is in agreement with the results of Said et al. (2012a, b) who calculated an annual mean T_{avg} of 20.6 °C, over the period 1974-2006. However, this is higher than the annual means of 20.3 °C (Mohamed and Beltagy 2009) over the period 1958-2008, and of 20.3 °C (Hendy 2018) over the period 1974-2006. This is, meanwhile, lower than the annual mean of 20.8 °C calculated by Shaltout et al. (2013). This difference in the calculated annual mean may be attributed to the different time spans of calculations or to the variant data sources.

The current study of long-term trends in air temperature variations reported that Alexandria experienced an annual increasing rate of +0.02 °C for its annual mean T_{avg} . This is consistent with the rate calculated by Mostafa et al. (2019) for Alexandria (+0.02 °C/yr) during the period 1960-2010. However, this rate is lower than the +0.06 °C/yr by Said et al. (2012a, b) for the period 1979-2011, the +0.04 °C/yr calculated by ElBessa et al. (2021) from 1979 to 2018 and by El-Geziry (2021) over the period 1980-2019. This is also lower than the +0.056 °C/yr rate calculated by Tonbol et al. (2018) for the period 2007-2016 in the Southern

Levantine. Meanwhile, the current pace is higher than Hendy (2018)'s estimate of $+0.01$ °C/yr for Alexandria from 1979 to 2016.

The results of this study revealed that the year 2018 as the year of maxima for the three examined air temperature categories. This is consistent with the results of El-Geziry (2021). Mohamed and Beltagy (2009) declared 2002 as the year of maximum annual mean over the period 1958-2008, and Hendy (2018) declared 1974 for the period 1974-2016.

The significance of increasing trends in the present study is in a very good agreement with those of Eid et al. (2019) who declared that the annual and seasonal air temperatures in Alexandria have significant increasing trends with 95% confidence.

Seasonal variations of both cold and warm T_{avg} affecting Alexandria revealed an increasing trend of $+0.02$ °C/yr, each. This is lower than the rates calculated by El-Geziry (2021) over the period 1980-2019, of $+0.08$ °C/yr (cold) and $+0.06$ °C/yr (warm). This difference may be attributed to the different data periods.

From an extreme perspective, results revealed no extreme low T_{avg} over the period of interest. 2018 and 2021 were the years of extremely high T_{avg} . Eid et al. (2019) declared 3 years of extremely low T_{avg} in Alexandria: 1967, 1983 and 1989, over the period 1960-2016. They also showed 3 years of extremely high T_{avg} : 2010, 2014 and 2016. On a seasonal basis, no low winter extreme event occurred in this study, and three years were recorded as extremely high: 2010, 2014 and 2015. 2010 and 2018 were the two years of extremely high winter T_{avg} (ElBessa et al. 2021) over the period 1979-2018. They recorded 1983 and 1992 as the years of extremely low winter T_{avg} . Summer extremely high T_{avg} years were 2018 and 2021 (present study) and 2010 and 2015 (ElBessa et al. 2021). The extremely low summer T_{avg} year, on the other hand, was in 1987 in the two studies.

Conclusion

Temperature data from 1957 to 2021 were used in this study to determine temperature variability and trends in Alexandria. Based on the analysis of the (T_{avg}), (T_{max}), and (T_{min}) data series, it is possible to conclude that the temperature of the area reflected general higher temperature variability, on different bases: monthly, annual and seasonal. A significant increase in air temperature was seen in all-time series when the trend equation, trend magnitude, and MK trend test were applied to the three considered air temperature categories in Alexandria. Hypothesis H_1 is highly common, and there is a minute chance that it will be rejected. Monitoring and analyzing the climate extremes in Alexandria should be the focus of future research. It should also be noted that the trend analysis was carried out using the parameters from the available station in the city territory. The presence of microclimate differences in Alexandria is influenced by a number of elements, including the degree of urbanization, topography hypsometry, hydrographic objects, and flora. Extreme climate events (aridity, drought - an unfavorable situation in agriculture), human health repercussions, and the decrease

or even extinction of terrestrial and marine ecosystems are just a few of the socio-economic impacts of climate change. For these reasons, this study highly recommends additional automatic weather stations to cover the large surface area of the City in order to monitor the required parameters for excessive analysis, which by the end, may guide the decision-makers to the actions needed to perform convenient mitigation and adaptation plans.

References

- Abdel-Shafy HI, El-Saharty AA, Regelsberger M, Platzer C (2010) Rainwater in Egypt: quantity, distribution and harvesting. *Mediterranean Marine Sciences* 11(2): 245–257.
- Abou-Mahmoud MME (2021) Assessing coastal susceptibility to sea-level rise in Alexandria, Egypt. *Egyptian Journal of Aquatic Research* 47(2): 133–141.
- Arghius V, Muntean L, Baciú N, Macicasan V, Arghius C (2020) Analysis of annual and seasonal air temperature trends in central part of Romania. *Present Environment and Sustainable Development (PESD)* 14(1): 51–61.
- Atilgan A, Tanriverdi C, Yucel A, Oz H, Degirmenci H (2017) Analysis of long-term temperature data using Mann-Kendall trend test and linear regression methods: the case of the southeastern Antolia region. *Scientific Papers, Series A-Agronomy* 60: 455–462.
- Bačević N, Valjarević A, Kićović D, Milentijević N, Ivanović M, Mujević M (2020) Analysis of air temperature trends: city of Podgorica (Montenegro). *University Thought Publications on Natural Sciences* 10(1): 31–36.
- Bonacci O, Bonacci D, Patekar M, Pola M (2021) Increasing trends in air and sea surface temperature in the Central Adriatic Sea (Croatia). *Journal of Marine Science and Engineering* 9(4): 358.
- Chen Y, Xu Z (2005) Plausible impact of global climate change on water resources in the Tarim River Basin. *Science in China Series D: Earth Sciences* 48(Jan): 65–73.
- Eid MM, Gad E, Abdel Basset H (2019) Temperature analysis over Egypt. *Al-Azhar Bulletin of Science* 30(2): 13–30.
- El Kenawy A, López-Moreno JI, McCabe MF, Brunsell NA, Vicente-Serrano SM (2015) Daily temperature changes and variability in ENSEMBLES regional models predictions: evaluation and intercomparison for the Ebro Valley (NE Iberia). *Atmospheric Research* 155(Mar): 141–157.
- El Kenawy AM, López-Moreno JI, Vicente-Serrano SM, Mekld MS (2009) Temperature trends in Libya over the second half of the 20th century. *Theoretical and Applied Climatology* 98(Jan): 1–8.
- ElBessa M, Abdelrahman SM, Tonbol K, Shaltout M (2021) Dynamical downscaling of surface air temperature and wind field variabilities over the Southeastern Levantine Basin, Mediterranean Sea. *Climate* 9(10): 150.
- El-Geziry TM (2021) Analysis of long-term rainfall and air temperature patterns in Alexandria (Egypt). *Arabian Journal of Geoscience* 14(Jun): 1199.
- Fontaine B, Janicot S, Monerie P (2013) Recent changes in air temperature, heat waves occurrences, and atmospheric circulation in Northern Africa: heat waves and atmospheric circulation. *Journal of Geophysical Research: Atmosphere* 118(15): 8536–8552.

- García-Ruiz JM, López-Moreno JI, Vicente-Serrano SM, Lasanta-Martínez T, Beguería S (2011) Mediterranean water resources in a global change scenario. *Earth Science Review* 105(3–4): 121–139.
- Gavrilov MB, Marković SB, Jarad A, Korać VM (2015) The analysis of temperature trends in Vojvodina (Serbia) from 1949 to 2006. *Thermal Science* 19(2): 339–350.
- Hamed AA (1983) *Atmospheric circulation over the south eastern of the Mediterranean Sea in relation with weather conditions and wind waves along the Egyptian Coast*. Ph.D. Thesis. Egypt: Alexandria University.
- Hasanean HM (2001) Fluctuations of surface air temperature in the Eastern Mediterranean. *Theoretical and Applied Climatology* 68(Mar): 75–87.
- Hendy DM (2018) *Risk reduction of extreme climate changes on the coastal zone of Alexandria, Egypt*. Ph.D. Thesis. Egypt: Alexandria University.
- Ibrahim O, Mohamed B, Nagy H (2021) Spatial variability and trends of marine heat waves in the Eastern Mediterranean Sea over 39 years. *Journal of Marine Science and Engineering* 9(6): 643.
- IPCC (2013) *Climate change 2013: the physical science basis*. Cambridge, UK: Cambridge University Press.
- Jonathan KH, Raju PS (2017) Analysis of rainfall pattern and temperature variations in three regions of Sultanate of Oman. *International Journal of Civil Engineering and Technology* 8(2): 173–181.
- Kale S (2017) Climatic trends in the temperature of Çanakkale City, Turkey. *Natural and Engineering Sciences* 2(3): 14–27.
- Maiyza I, El-Geziry T, Maiyza H, Kamel M (2011) Climatological trend of air temperature anomalies in the South Eastern Mediterranean Sea. *JKAU: Marine Sciences* 22(2): 55–65.
- Marin L, Birsan M, Bojariu R, Micu DM, Manea A (2014) An overview of annual climatic changes in Romania: trends in air temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed during the 1961–2013 period. *Carpathian Journal of Earth and Environmental Sciences* 9(4): 253–258.
- Masson V, Zhai P, Pirani A, Connors SL, Pean C, Berger S, et al. (2021) IPCC, 2021: summary for policymakers. In *Climate Change 2021: The Physical Science Basis*. UK: Cambridge University Press.
- Mohamed EE-S, Beltagy AI (2009) Analysis of long-term air temperature in Alexandria. *Egyptian Journal of Aquatic Research* 35: 461–474.
- Mostafa AN, Wheida A, El Nazer M, Adel M, El Leithy L, Siour G, et al. (2019) Past (1950–2017) and future (–2100) temperature and precipitation trends in Egypt. *Weather and Climate Extremes* 26(Dec): 100225.
- Paeth H, Born K, Girmes R, Podzun R, Jacob D (2009) Regional climate change in Tropical and Northern Africa due to greenhouse forcing and land use changes. *Journal of Climate* 22(1): 114–132.
- Piticar A, Ristoiu D (2014) The influence of changes in teleconnection pattern trends on temperature and precipitation trends in northeastern Romania. *Riscuri și Catastrofe* 14(1): 109–122.
- Said MA, El-Geziry TM, Radwan AA (2012a) Long-term trends of extreme climate events over Alexandria region, Egypt. In *Proceedings of LANDSI Conference Lebanon*, 286–293.
- Said MA, Moursy Z, Radwan A (2012b) Climatic change and sea level variations off Alexandria, Egypt. In *International Conference on Marine and Coastal Ecosystems (MarCoastEcos2012)*. Albania, Poster Session: C38, Poster: Th16A.

- Shadmani M, Marofi S, Roknian M (2012) Trend analysis in reference evapotranspiration using Mann-Kendall and Spearman's Rho tests in arid regions of Iran. *Water Resource Management* 26(Oct): 211–224.
- Shaltout M, El Gindy A, Omstedt A (2013). Recent climate trends and future scenarios along the Egyptian Mediterranean coast. *Geofizika* 30(1): 19–41.
- Singh D, Gupta RD, Jain SK (2015) Study of daily extreme temperature indices over Sutlej Basin, N-W Himalayan Region, India. *Global NEST* 17(2): 301–311.
- Sneyers R (1990) *On the statistical analysis of series of observations (WMO No. 415)*. WMO Technical Note.
- Sridhar N, Bhole V (2015) Climate change in a mega city: a temporal analysis of long term temperature variability in Greater Hyderabad, India. *Journal of International Academic Research for Multidisciplinary* 3: 19–28.
- Subarna, D (2017) Analysis of long-term temperature trend as an urban climate change indicator. *Forum Geografi* 31(2): 196–208.
- Thapa A, Silwal A, Gautam SP, Nepal CK, Bhattarai S, Timsina D (2021) Surface air temperature trends in Kathmandu Valley for 2011-2017. *BIBECHANA* 18(2): 95–104.
- Tonbol KM, El-Geziry TM, ElBessa M (2018) Evaluation of changes and trends in air temperature within the Southern Levantine basin. *Weather* 73(2): 60–66.
- Türkeş M, Sümer UM, Demir İ (2002) Re-evaluation of trends and changes in mean, maximum and minimum temperatures of Turkey for the period 1929-1999: temperature trends in Turkey. *International Journal of Climatology* 22(8): 947–977.
- Zaki A, Swelam A (2017) *1st report on the climatology of Nile Delta, Egypt*. Egypt: Ministry of Agriculture and Land Reclamation.