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Variability and Trend Analysis of Temperature in Egypt

E. Fouad, M. EN. Adam and M. Saied*

Physics Department, Faculty of Science, South Valley University, Qena

CLIMATIC change is one of the most important issues of present times, therefore, worldwide interest in global warming and climate change has led to numerous trend detection studies. This study focuses on the variability and trends of the monthly, seasonal and annual temperatures in Egypt over the period 1901-2016 (116 years). Variability of temperature has been computed using mean (μ), standard deviation (σ) and coefficient of variation (CV). The Mann-Kendall (MK) test was used to detect the trends of temperature with Sen's slope estimator. One of the main results of this study is the confirmation of the increasing trend of temperatures in Egypt. There was a definite positive trend for the annual temperature over this period with an increase of 0.87°C. Seasonally, the highest warming trends were observed in the summer season with an increase of 1.35 °C and the lowest warming trend in the winter season with an increase of 0.46 °C. There is a clear increasing trend of the temperatures in Egypt for the studied period. This, in turn, will aid in decision-making regarding future funding and establishing research related to climate change in Egypt.

Keywords: Climate Change, Temperature, Variability, Trend, Mann–Kendall Test, Egypt.

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable periods" [1]. A concern in climate change and global warming by the international community, non-government organizations and governments have brought great interest to climate scientists leading to several studies on climate trend detection at the global and regional scale [2, 3].

Numerous studies have indicated the direction and significance of temporal trends of temperature at various spatial scales from the global to the local [4-7]. They all pointed to the fact that there is a generally upward (warming) trend in the global mean surface temperature at a rate fluctuating between 0.3°C and 0.6°C over the last century. Nevertheless, this large-scale trend is not spatially or temporally identical[8]. For instance, upward trends in land-based locations in winter are generally higher than marine observatories, particularly at higher latitudes [9].

Recent evidence and predictions from computer models indicate that climate changes are accelerating and will lead to wide-ranging shifts in climate variables [10, 11]. The overall temperature throughout the African continent has increased by approximately 0.7°C during the 20th century, and the Intergovernmental Panel on Climate Change (IPCC) has predicted that temperatures across Africa are expected to increase by 2 – 6°C within the next 100 years [12, 13].

Generally, the impacts of climate change and climate variability are projected to have enormous and devastating global consequences on the global scale, but the most adverse impacts are predicted to occur in developing countries due to their fewer resources to cope with, and adapt to, the changing conditions, which is due to their geographic location and their over-reliance on agriculture, which is a climate-sensitive sector [10, 14, 15].

Africa is one of the most vulnerable continents to climate change and climate variability. Africa is the largest tropical landmass, split almost equally

*Corresponding author:m_saied@sci.svu.edu.eg
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by the equator into both hemispheres [16]. Due to its extensive landmass, stretching from about 35°N to 35°S, climate regimes vary from humid equatorial regimes, arid and semi-arid regimes to sub-tropical Mediterranean-type climates with different degrees of temporal variability in rainfall and temperature [17-19]. Climate change is expected to make the eastern parts of Africa wetter, while other regions like the southern and northern parts of Africa will get drier and more adversely affected by the changes [17, 18].

Climate change-associated risks could pose serious threats to Egypt. Sea-level rise (SLR) and temperature increases due to climate change are the direct threats that climate change poses to Egypt. These impacts could adversely affect Egypt's economy, ecosystems and human health [20-22]. For more than two decades, Egypt has been conducting temperature change studies. This includes Time series trends of land surface temperatures in Egypt: a signal for global warming has been studied by [23], The study of recent temporal and spatial temperature changes in Egypt [24] and Unidirectional trends in annual and seasonal climate and extremes in Egypt [25].

In Egypt, the temperature has been observed by meteorologists and climatologists to have risen and people begin to experience the impacts of warming. Egypt is a country that stands to lose from warming or rise in temperature: its development is based on agriculture; energy is supplied mostly through hydropower generation and a greater part of its coastal society could disappear if when sea level would rises. Generally, the study aimed to characterize the warming trends through a detailed analysis of changes in surface temperature observations in the last 116 years (1901-2016), as a precursor of climate change in Egypt.

Description of Data

Study area

Egypt lies primarily between latitudes 22° and 32°N, and longitudes 25° and 35°E, located in the northeast of Africa occupies an area of 1,010,408 km^2 (Figure 1). The country is bounded by the Mediterranean Sea to the north and the Red Sea to the east. The topography of Egypt varies from 133 m below the mean sea level at the deepest point of the Qattara Depression to 2629 m in Mount Catherine. Geographically, Egypt can be divided into four regions, namely, the Nile Valley and Delta, the Eastern Desert,

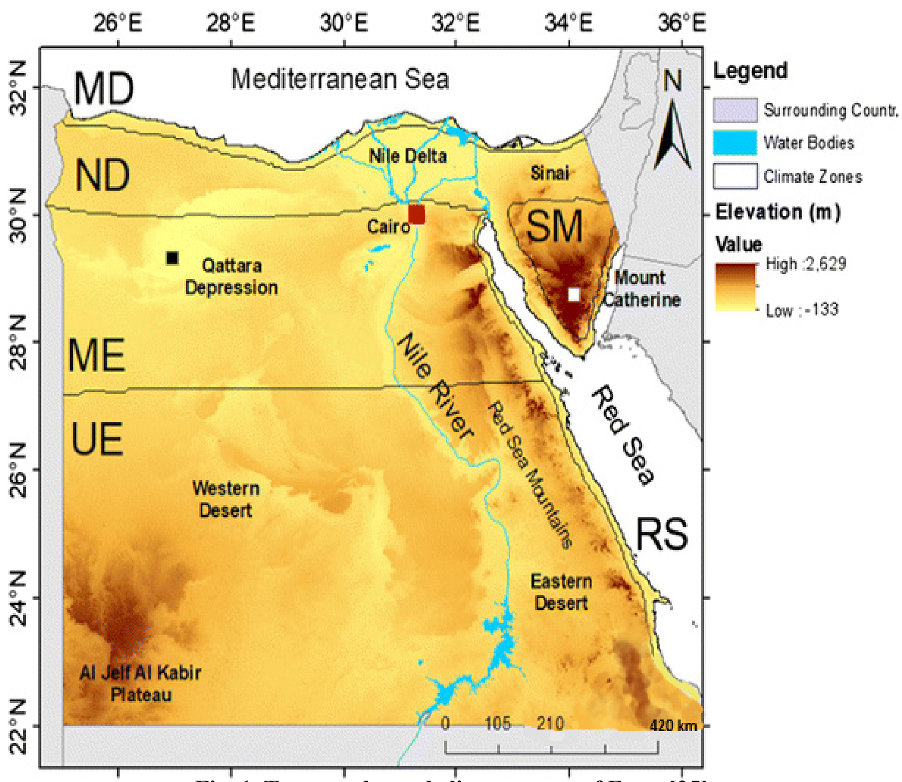


Fig. 1. Topography and climate zones of Egypt[25].

the Western Desert which is a part of the Sahara Desert, and the Sinai Peninsula. About 97% of the total population of Egypt lives in the Nile Valley and Delta which represents only 4% of the total area of Egypt [25, 26].

Climatologically, the land of Egypt can be classified into six regions (Fig. 1): (a) the Mediterranean (MD) in the north of Egypt along the Mediterranean shores, which receives the highest annual rainfall of 200 mm; (b) the Nile Delta (ND) in the downstream of the Nile close to the Mediterranean zone and extends to the Sinai Peninsula to the northeast of Egypt which receives an annual average rainfall of about 25 mm; (c) the Middle Egypt (ME) which ranges between latitude 27.2° N and 30° N and receives an annual average rainfall of 10 mm; (d) Upper Egypt (UE), mostly in the western desert where the annual average rainfall is nearly zero; (e) the Red Sea (RS), a narrow strip confined by Red Sea mountains and the Red Sea; and (f) the Sinai Mountains (SM), the mountain area in the northeast of Egypt where the annual mean rainfall is more than 100 mm[25, 27]. According to the Köppen classification, the climate of Egypt is the hot desert climate (BWh). Therefore, the weather is mostly dry all around the year [28].

Data Sources and Processing

The monthly data from 1901 to 2016 has been aggregated to prepare seasonal and annual temperature series in Egypt using data obtained from the Climate Research Unit (CRU TS 3.24.01) at the University of East Anglia with high-resolution (0.5^0 x 0.5^0) grids [29]. The monthly data were averaged to calculate the annual and seasonal temperatures. The data were processed to prepare using excel and different software during the study.

Methodology

Statistical Analysis

In this study, temperature variability in Egypt over the long period 1901-2016 have been computed using mean (μ), standard deviation (σ) and coefficient of variation (CV).Data analysis was undertaken using XLSTAT software and excel spreadsheet [30].

Trend Detection

Mann-Kendall test is a non-parametric test commonly employed to detect monotonic trends in series of environmental data, climate data, or hydrological data. MK test has been used to detect the presence of monotonic (increasing or decreasing) trends in the study area and whether the trend is statistically significant or not. Since there are chances of outliers to be present in the dataset, the non-parametric MK test is useful because its statistic is based on the (+ or -) signs, rather than the values of the random variable, and therefore, the trends determined are less affected by the outliers [31]. The MK test statistic 'S' is calculated based on [32], [33] and [34] using the formula:

$$S=\sum_{i=2}^{n}\sum_{j=1}^{i-1}\mathrm{sign}(x_i-x_j)$$

Where n is the length of the data set, and are two generic sequential data values and the function sign assumes the following values:

$$\mathrm{sign}(x_i-x_j)=\begin{cases}1, & \text{if } (x_i-x_j)>0,\\ 0, & \text{if } (x_i-x_j)=0,\\ -1, & \text{if } (x_i-x_j)<0.\end{cases}$$

The S statistic therefore represents the number of positive differences minus the number of negative differences found in analyzed time series. Under the null of that there is no trend in the data no correlation between considered variable and time, each ordering of the data set is equally likely. Under this hypothesis the statistic S is approximately normally distributed with the mean E(S) and the variance Var (S) [33] as follows:

$$E(S) = 0$$

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

Where n is the length of the times-series, tp is the number of ties for the pth value and q is the number of tied values i.e., equals values. The second term represents an adjustment for tied or censored data. The standardized test statistic Z is given by:

$$Z=\begin{cases}\frac{S-1}{\sqrt{Var(S)}} & \text{if } S>0,\\ 0 & \text{if } S=0,\\ \frac{S-1}{\sqrt{Var(S)}} & \text{if } S<0.\end{cases}$$

The presence of a statistically significant trend is evaluated using the Z value. This statistic is used to test the null hypothesis such that no trend exists. A positive Z indicates an increasing trend in the time-series, while a negative Z indicates a decreasing trend. To test for either increasing or decreasing monotonic trend at p significance level, the null hypothesis is rejected if the absolute value of Z is greater than Z (1-p/2); where Z (1-p/2) is obtained from the standard normal cumulative distribution tables. In this work, the significance levels of 0.01, 0.05 and 0.1 were applied, and the significant level p-value was obtained for each analyzed time-series.

Sen's Slope (b) estimation test computes both the slope (i.e. the linear rate of change) and intercept according to Sen's method. The magnitude of the trend is predicted by [35, 36] slope estimator methods [37]. A positive value of b indicates an 'upward trend' (increasing values with time), while a negative value of b indicates a 'downward trend'. Here, the slope of all data pairs [35] is computed as from:

b = Median [(x_j-x_i)/(j-i)],foralli<J

Where is the slope between data points and ; measured at times j and i; respectively.

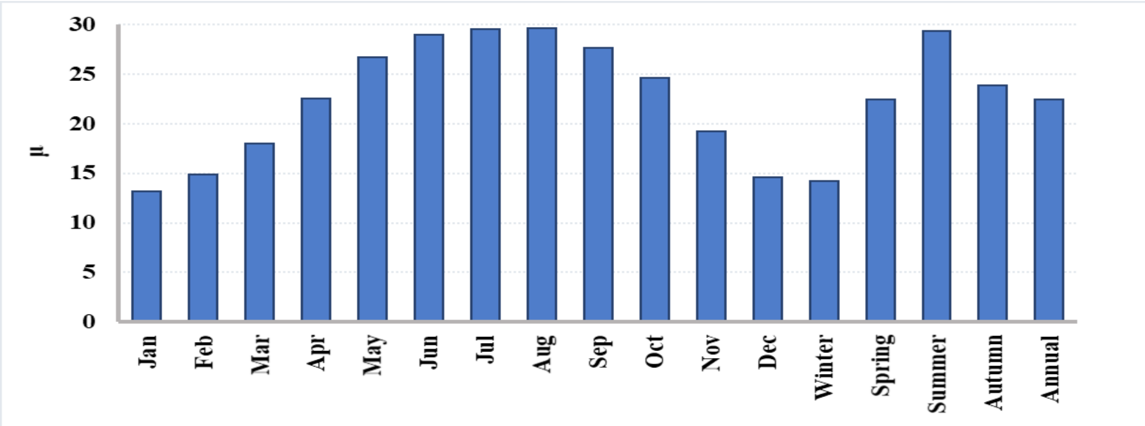


Fig. 3. Mean temperatures in Egypt from 1901 to 2016.

TABLE 1. Statistics of the monthly, seasonal and annual temperature at Egypt, 1901-2016.

Series	μ	σ	CV
Jan	13.22	1.02	7.74
Feb	14.87	1.29	8.66
Mar	18.03	1.32	7.31
Apr	22.55	1.05	4.65
May	26.65	1.00	3.77
Jun	28.99	0.86	2.97
Jul	29.53	0.76	2.56
Aug	29.62	0.86	2.89
Sep	27.62	1.00	3.61
Oct	24.61	1.12	4.54
Nov	19.26	1.24	6.44
Dec	14.62	1.05	7.17
Winter	14.24	0.74	5.22
Spring	22.41	0.75	3.34
Summer	29.38	0.68	2.32
Autumn	23.83	0.82	3.44
Annual	22.46	0.58	2.58

Results and Discussion

Statistics and Variability Analysis

From the temperature data, mean temperature (μ), along with their standard deviation (σ) and coefficient of variation (CV) has been statistically computed for each month,seasonand year for the period 1901-2016 (Table 1). The standard meteorological definition was used to define the seasons: Winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and autumn (September, October, and November).

It is clear from Table 1 and Fig. 3 that, the mean monthly temperature is highest in August 29.62 °C and lowest in January 13.22 °C. The mean seasonal temperature is highest in summer (29.38 °C) and lowest in winter (14.24 °C) and the mean annual temperature is 22.46 °C. The coefficient of variation for monthly temperature is highest in February (8.66 %) and lowest in July (2.56 %). The coefficient of variation is higher in winter season (5.22 %) than in summer season (2.32 %) and the coefficient of variation for annual temperature is (2.58 %).

Trend Analysis

The MK test and Sen's slope estimator were applied to the time-series data from 1901 to 2016 for Egypt (Table 2). The results of the standardized test statistics Z, significance level P-value and slope b; corresponding to the temperature variables trend analyzed in this study (Fig. 4).

Table 2 and Fig. 4 are clear that the MK test confirmed that the positive trend observed is statistically significant. A statistically significant increasing trend was obtained for the annual and seasonal temperatures at 5 % and 1 % levels of significance. All months show a significant increasing trend except November and December months which show a non-significance increasing trend.

The MK test confirmed that the annual temperature shows an increasing trend, which is statistically significant at 1 % level of significance (Fig. 5). A linear fit to the annual temperature confirms large trends of 0.0075 °C /year. This trend corresponds to an increase of 0.87 °C in the total period analyzed (1901-2016) of annual temperature.

The seasonal temperatures and trend line in Egypt over the period from 1901 to 2016, see Fig. 6. In the climatic seasons, we observe a different tendency of temperature change, Where the temperature time-series in Egypt for the whole period analyzed showed an increasing trend statistically significant at $P < 0.01$, $P < 0.05$ and $P < 0.1$ in all the seasons.

The winter temperature shows an increasing trend, which is statistically significant at $P < 0.1$ level with an increase of 0.46 °C. The spring temperature shows an increasing trend, which is statistically significant at $P < 0.01$ level with an increase of 0.92 °C. The summer temperature shows an increasing trend, which is statistically significant at $P < 0.01$ level with an increase of 1.35 °C. The autumn temperature shows an increasing trend, which is statistically significant at $P < 0.01$ level with an increase of 0.7 °C.

The monthly temperatures and trend line in Egypt over the period from 1901 to 2016 (Fig.7). The MK test confirmed that the positive trend observed is statistically significant in practically all months except November and December are not statistically significant. A Statistically significant at $P < 0.01$ level increases in temperature were noted for April, May, June, July, August and September months. A Statistically significant at $P < 0.1$ level increases in temperature were noted for January month, while February, March and October months at 0.1 level.

The monthly temperature shows the largest increase trend of 0.0146 °C /year with an increase of 1.66 °C in September month, while November temperature is very little increase trend of 0.0004 °C /year with an increase of 0.05 °C in the total period analyzed (1901-2016).

TABLE 2.Mann-Kendall trend test results (Z and p-value) and the slope b.

Series	Z	P-value	b
Jan	0.117	0.064	0.0054
Feb	0.094	0.133	0.0057
Mar	0.101	0.108	0.0059
Apr	0.175	0.005	0.0088
May	0.212	0.001	0.0096
Jun	0.250	< 0.0001	0.0095
Jul	0.332	< 0.0001	0.0118
Aug	0.346	< 0.0001	0.0132
Sep	0.333	< 0.0001	0.0146
Oct	0.087	0.169	0.0045
Nov	0.007	0.914	0.0004
Dec	0.025	0.687	0.0013
Winter	0.114	0.071	0.0037
Spring	0.248	< 0.0001	0.0086
Summer	0.360	< 0.0001	0.0112
Autumn	0.166	0.008	0.0063
Annual	0.279	< 0.0001	0.0075

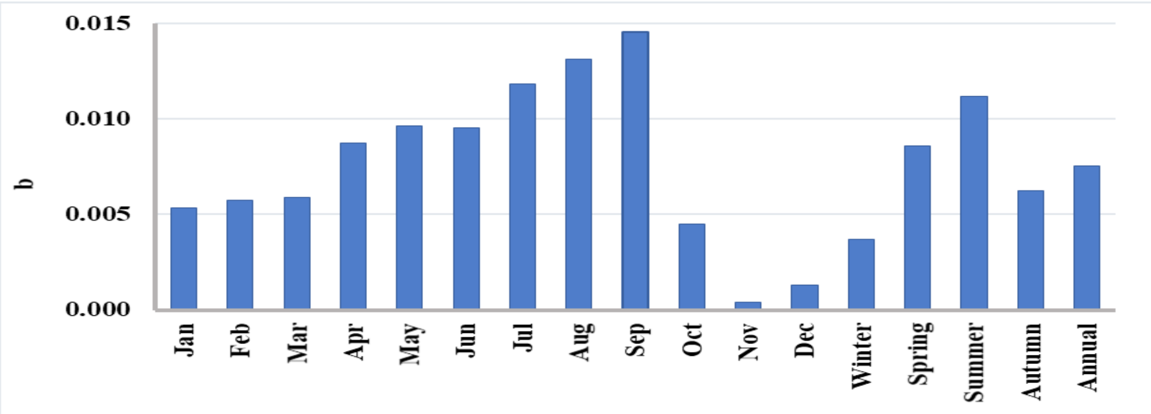


Fig. 4.The Sen's slope estimator for temperature in Egypt from 1901 to 2016.

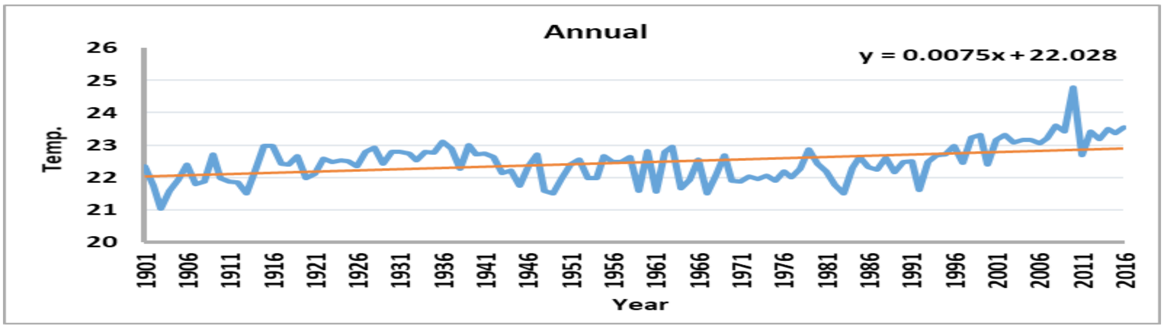


Fig. 5. Annual temperature trend in Egypt from 1901 to 2016.

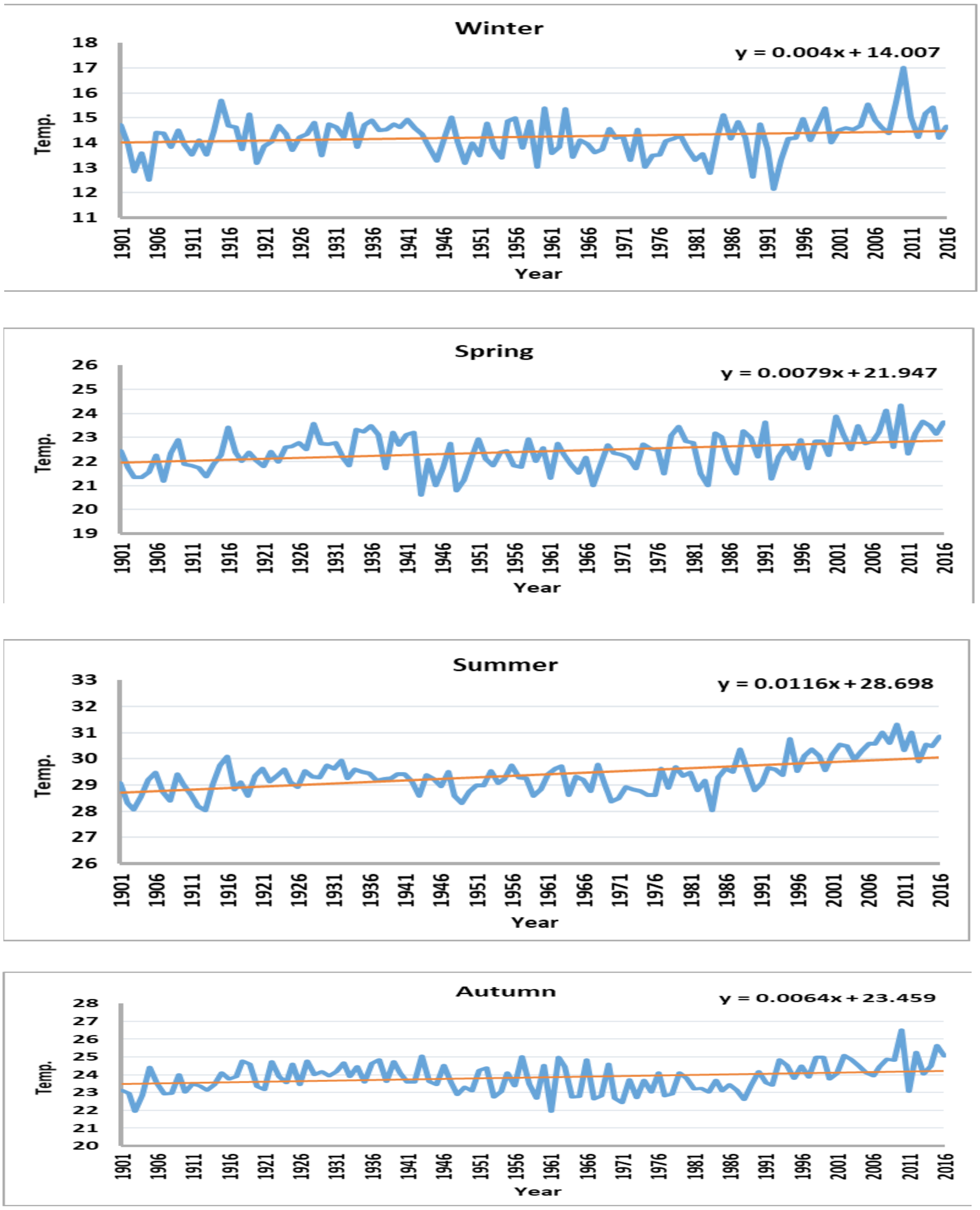
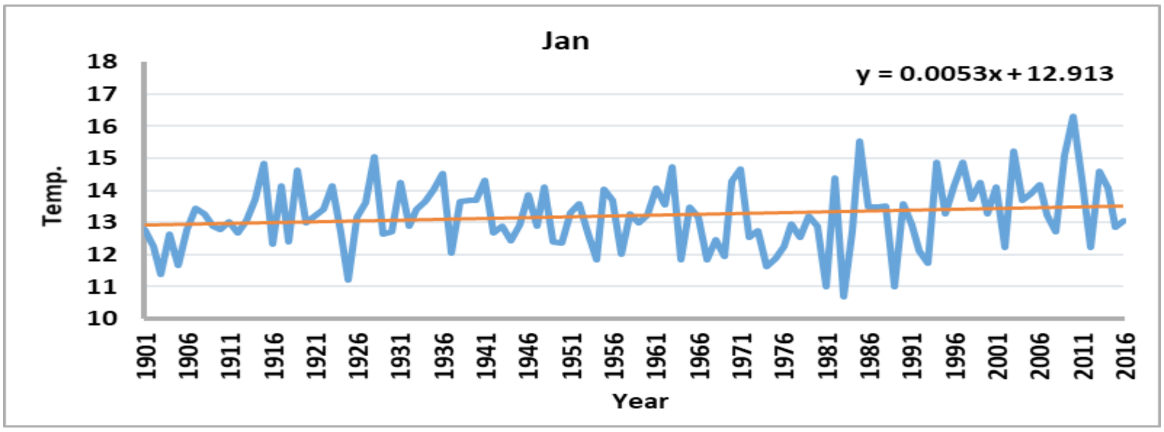
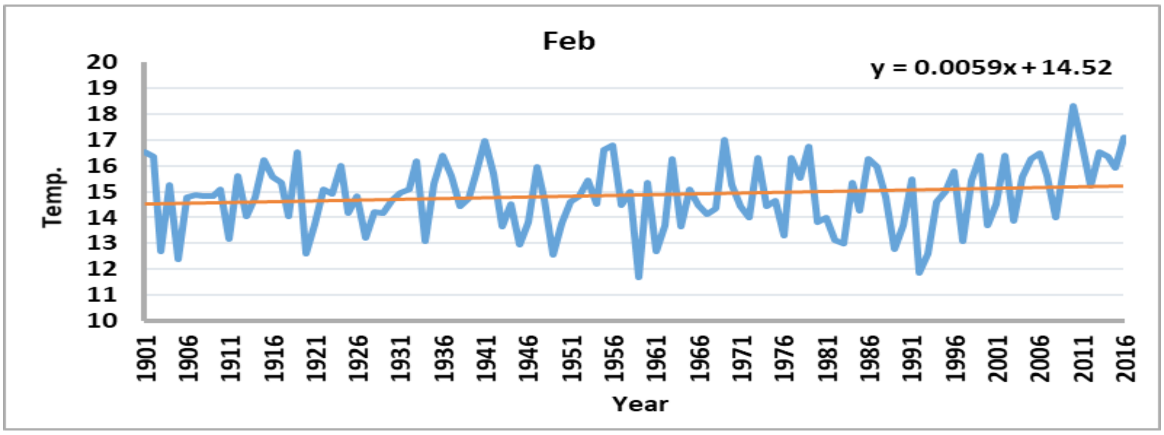
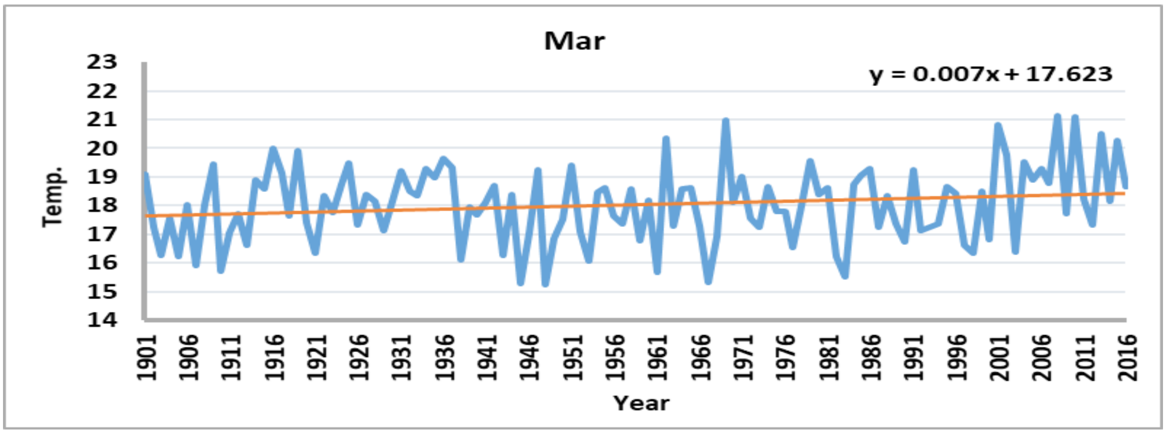
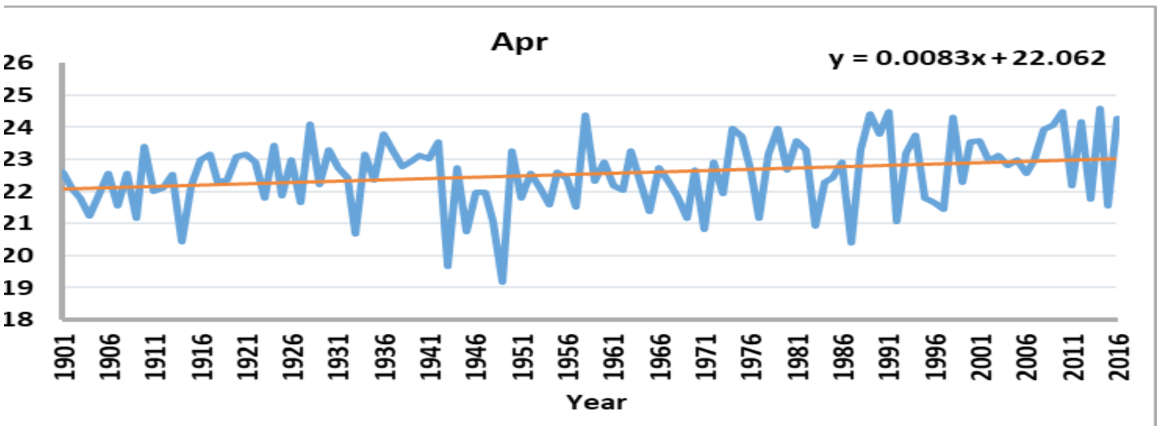


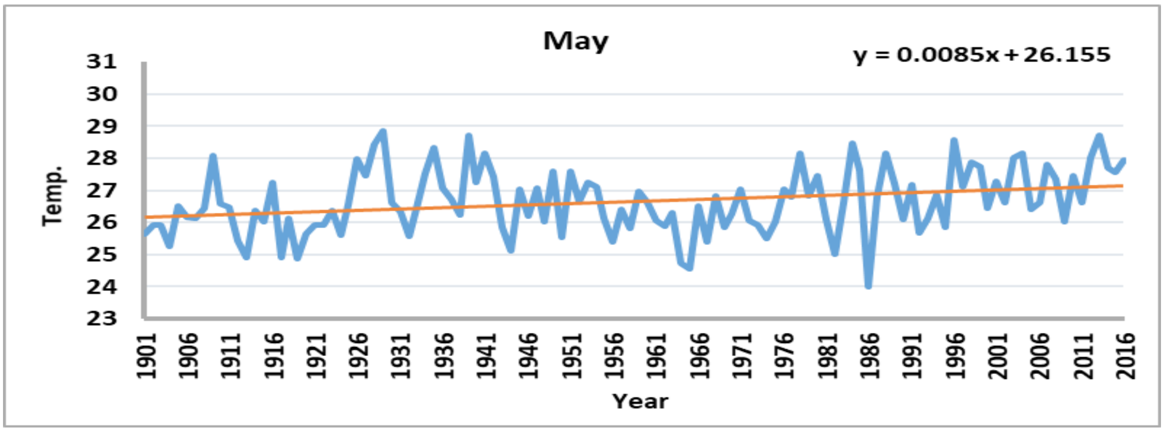
Fig. 6. Seasonal temperature trends in Egypt from 1901 to 2016.

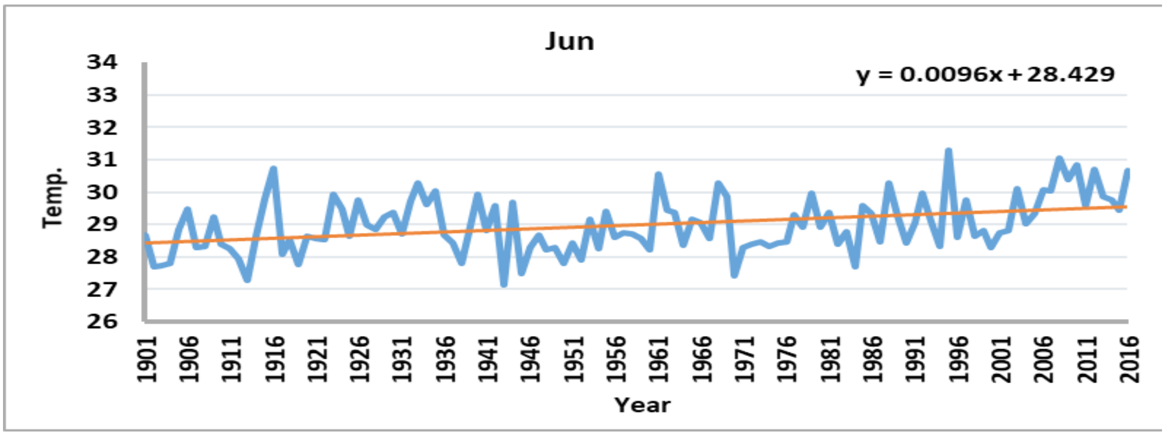

Jan
y = 0.0053x + 12.913
Temp.
Year

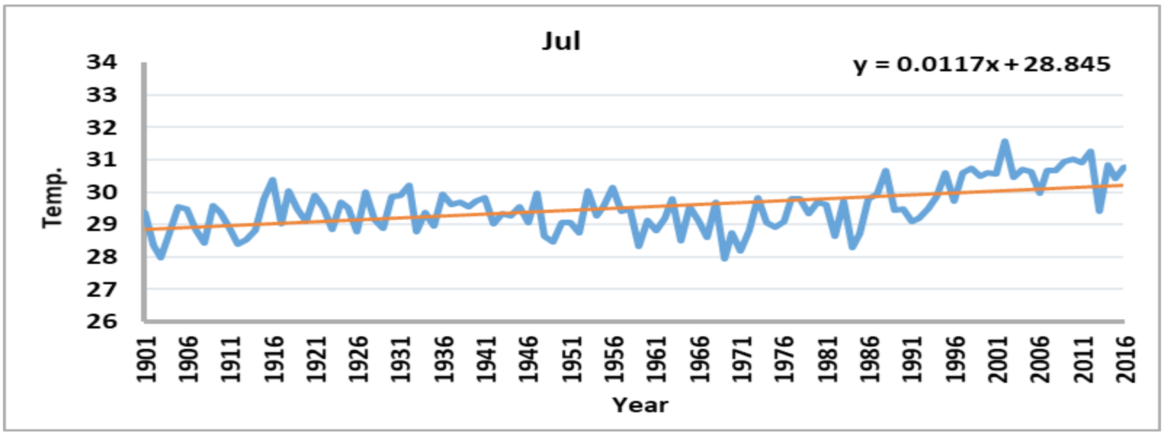

Feb
y = 0.0059x + 14.52
Temp.
Year

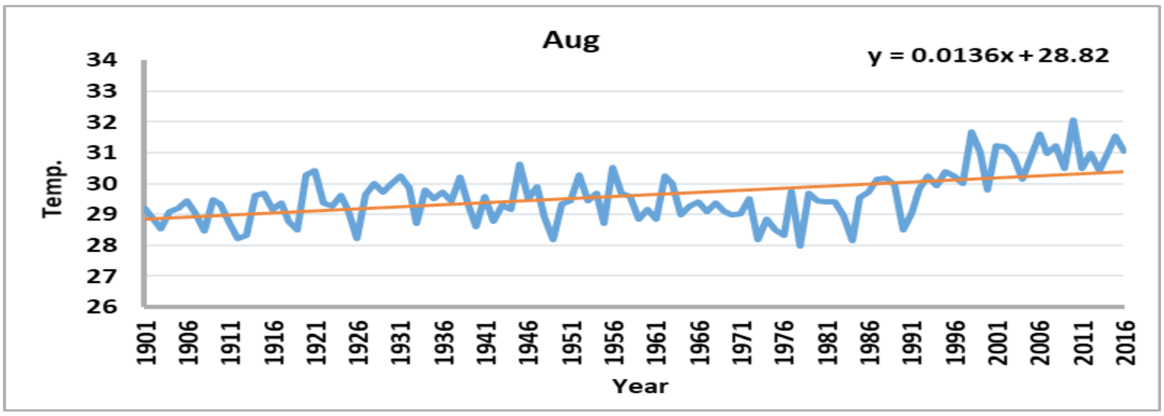

Mar
y = 0.007x + 17.623
Temp.
Year


Apr
y = 0.0083x + 22.062
Year


May
y = 0.0085x + 26.155
Temp.
Year


Jun
y = 0.0096x + 28.429
Temp.
Year


Jul
y = 0.0117x + 28.845
Temp.
Year


Aug
y = 0.0136x + 28.82
Temp.
Year

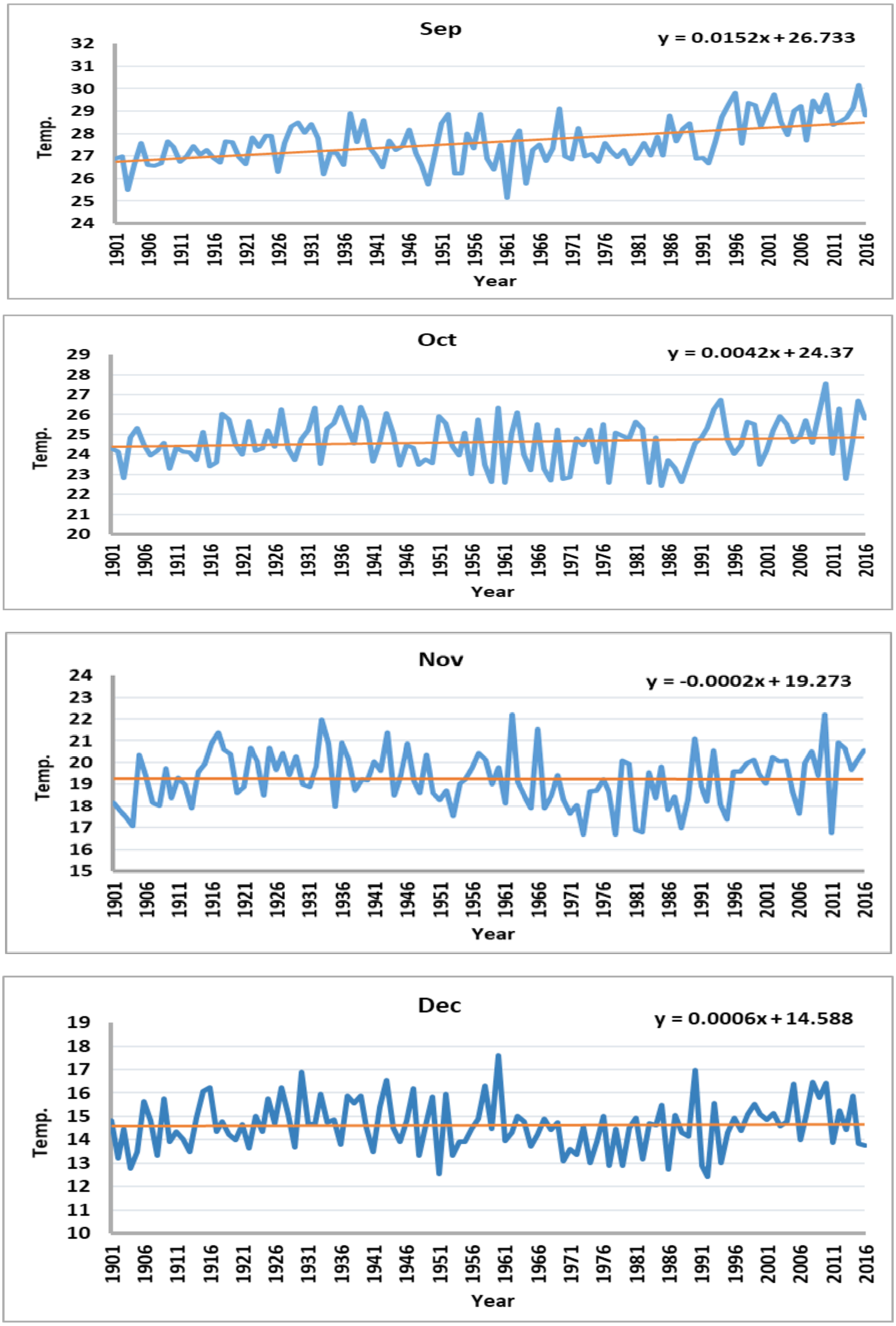


Fig. 7. Monthly temperature trends in Egypt from 1901 to 2016.

Conclusions

Since the last century changed climate adversely affects social, economic activities in developing and developed countries alike. This fact attracted the attention of scientists, climatologists, and researchers on a global to regional scale. This study investigated seasonal and annual climatic variability in Egypt based on mean temperature over the period 1901-2016 (116 years) has been computed using mean (μ), standard deviation (σ) and coefficient of variation (CV). Furthermore, the Mann-Kendall (MK) test was used to detect the trends of temperature with Sen›s slope estimator.

One of the main results of this study is the confirmation of the increasing trend of the mean annual, seasonal and monthly temperature in Egypt. There was a definite positive trend for the mean annual temperature over the long period (1901–2016) with an increase of 0.87 ℃. A tendency has also been observed towards warmer years, where the highest warming trends were observed in the summer season with an increase of 1.2735 ℃ and the lowest warming trend in the winter season with an increase of 0.46 ℃. Most trends computed understudy correspond with the global finding, as far as the trend for annual temperatures is concerned.

Egypt must confront the challenge of climatic change and work with the international community in order to reduce the impact of climatic change. Increasing public awareness is very important about the impacts of climatic change on the environment and human health. The goal should be clean technology to reduce emissions. A wide of strategic policy measures will be required for mitigation (actions are taken to reduce the amount of greenhouse gases pumped into the atmosphere and thus the severity of temperature rises) and adaptation (actions are taken to prepare for what are probably its inevitable effects).

Finally, we would support a suggestion that the objective of a better understanding of the phenomenon of global warming can be realized by a collaboration of specialists from various disciplines and backgrounds, who can give detailed interpretations, explanations and sources of uncertainties for each subject related to this phenomenon. We are grateful for the comments and suggestions made by the Referees that make the work presented in this paper more complete.

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