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Modelling Monthly and Annual Trends of the Monthly Air Maximum Temperature in Ndjamena, Chad, Over the Climatic Period 1961-1990

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The present article models monthly and annual trends of the monthly air maximum temperature in Ndjamena over the climatic period from 1961 to 1990. Monthly mathematical mean values over the period of this parameter has been calculated with their corresponding standard deviations. High values were registered from March to June, the beginning of the rainy season in the locality, and low values – during the dry season, from December to February. Its interval of variation was from 32.3°C in January to 41.0°C in April. Concerning the standard deviation, its interval of variation was from 0.9°C in April to 1.8°C in January, February and December. Deviations of the monthly air maximum temperatures from their corresponding mathematical mean values were calculated for each month over the climatic period. Their time trends were modeled by the least squares method.

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Analysis of the configuration their clouds of points in rectangular coordinates systems has shown that all monthly trends were according to the linear relationship. The coefficients of the obtained regression lines were mostly 0.1. This low value indicates that the time trend of the air maximum temperature was not significant to produce notable impacts on the environment in the considered locality. Similar treatments were applied to annual trends. The results were qualitatively the same. Thus, it is obviously clear during this climatic period no thermal perturbations to bring significant impacts to the environment were observed. But the study has revealed a weak tendency to the rise of the maximum air temperature in Ndjamena, particularly by the end of the period.

Keywords: Air maximum temperature; climatic period; monthly and annual trends; mathematical mean values; standard deviations; deviations of the monthly air maximum temperature from their mathematical mean values; linear relationship; least squares method; linear regression.

1. INTRODUCTION

In developing countries mainly tropical areas, just few people pay attention the air temperature. This could be explained by the fact that in these zones this parameter varies in a narrow interval. This situation is also complicated by the lack of meteorological stations and required instruments, qualified personal. Moreover, the instruments are not always of required quality. Nowadays, many people have started feeling the world global warming. Frequently, deaths, particularly among aged, vulnerable persons and kids, caused by strong heat are registered, [1,2]. Not only human beings, these excessive high temperatures affect also animals and impact agro-pastoral activities. For recall, excessive high temperatures of the air were caused many deaths in 2003 in France and other countries, [3,4]. Lest us remember the ethiopian tragedy of the years 1980s. Global changes in extreme daily temperatures have been investigated for many areas, [5,6].

The air temperature could be characterized as the level of warmness in the air. Based on the molecular physic, the temperature could be defined as the average kinetic energy of all the molecules in a considered space.

The temperature is not a constant parameter. It changes permanently. Usually, it is represented by a function of the coordinates (x,y,z) of the considered locality and the time t of the observation. If T is the temperature, one may write this function as, T=T(x,y,z,t).

For already almost a century, populations all-over the world cry about the global warmness in the Earth. In fact, due to human activities, the global temperature of our planet increases from year to year, [7]. This is effectively visible in many localities around the world. Moreover, land surveys indicate that deserts grow continuously and occupy more territories. At the same time, air temperature increases permanently, leading to excessive evapotranspiration, whence the consistent reduction of the soil water reserve. Other phenomena, between others, cyclones, hurricanes and droughts, could be seen as the manifestations of the excessive warmness in a given locality. Face to this situation and to prevent a planetary humanitarian catastrophe, daily survey of the time trends of the thermal regime of the atmosphere and their quantifications should be regularly made. Unpublished works of researchers in Bed Dagan, Israel, have revealed that an increase of the air temperature by about 0.5 °C could reduce the production of avocado by some hundreds of kilograms. Thus, it is obvious that the menace is real.

Concerning the increase of the air temperature, previous works have revealed that Ndjamena and surroundings are not yet exposed to tsunamis, [8,9], but carefully use of lands and regular environmental surveys were strongly recommended.

In his M. Sc. thesis, Hamid has used the same data to investigate the time trends of the maximal air temperature in Ndjamena during two consecutive climatic periods, 1961-1990 and 1991-2020, [1]. His approach consisted of dividing each period into six equal sub-periods in which he calculated the sub-periods means, corresponding standard deviations and their time trend models. In the present work covering only one climatic period, similar characteristics were calculated but for each month and their time trends over the period were investigated. Thus, obviously that our approach should provide more deep information about the time variation of the considered parameter.

This work concerns a statistical investigation of the monthly trends of the air maximum temperature in Ndjamena. The choice of this locality is dictated by the fact that the country biggest and well equipped meteorological station is situated there. Thus, the treated data should be considered more representative. It covers one climatic period, i.e. 30 years, from 1961 to 1990. The chronological series are regular, without missed data.

The present work is divided into five sections. The first and present section is the introduction to the problematic of our study. The second one concerns the presentation of the data and methodology of their treatment. The results and analysis are presented in the third section. Conclusion and eventual recommendations are found in the fourth section. At last, references in alphabetic order are in the fifth one [10].

1.1 Data and Methodology

Data

The present data comes from the meteorological station at the international airport in Ndjamena, Chad. It is understandable that it is well equipped with good qualified specialists and instruments compared to other localities. We dare believe that they perfectly know the importance of their work. The data has been already treated and presented in tabular forms as monthly averages. These tables do not present missed data.

Chad is a continental country situated in the central part of Africa in the sahelian area. It is bordered in the North by Libya, in the East by Sudan, in the South East by Central African Republic, in the South by Cameroon, in the West by Nigeria and the North West by Niger. Ndjamena is the capital of the country and is situated in its southern eastern part.

The air maximum temperature is measured by the maximal thermometer and compared to the values from the psychrometer and thermograph for eventual corrections. Observations are usually made five times a day, according to the World Meteorological Organization, WMO. At the end of the day, daily averages are determined and at the end of each month, monthly averages, θ, are calculated. Used instruments are placed in the meteorological cabin at 2 meters above the earth surface.

The values of the monthly air maximum temperature in Ndjamena are presented in Table 1. Further computations are based on this table.

2. METHODOLOGY

The used methodology is based on statistics. For each month, mathematical mean values and corresponding standard deviations were calculated and presented in tabular forms. These monthly mathematical mean values have permitted us to determine the deviations of the monthly air maximum temperatures from their corresponding mathematical mean values over the whole climatic period. These deviations were also presented in a tabular form. Obviously that some should be positive and others – negative.

Experimental points $M_i(t_i, \Delta\theta_i)$, the time t_i in the axis of abscissa representing the years, $\Delta\theta_i$ in the axis of ordinates representing the deviations of the monthly air maximum temperatures from their corresponding mathematical mean values over the climatic period, were plotted, i = 1, 2, 3, …, 30. The configurations of the obtained clouds of points were analyzed in order to determine the form of the relationship between the two parameters. At last, the mathematical formulas of these founded relationships were established using the least squares method whose principle is as recalled below.

Let the founded relationship being the next function of order n:

$$y = f(x) = a_n x^n + a_{n-1} x^{n-1} + a_{n-2} x^{n-2} + \ldots + a_1 x + a_0. \tag{2.1}$$

It is clear that (2.1) has n+1 coefficients to be founded. Thus, we have to establish a system of n+1 equations to be solved for these coefficients. This system of equations comes from the derivations with regard to the coefficients of the next auxiliary function:

$$U(a_0, a_1, a_2, \ldots, a_n) = \sum_{i=0}^{n}\left(y_i - y_{exp}\right)^2 = \sum_{i=0}^{n}\left(a_n x_i^n + a_{n-1} x_i^{n-1} + a_{n-2} x_i^{n-2} + \cdots + a_1 x_i + a_0 - y_{exp,i}\right)^2, \tag{2.2}$$

where y_i is the value given by formula (2.1) and $y_{exp,i}$ – the experimental value of function y at the nod i.

Table 1. Climatic monthly air maximal temperature $\theta°C$ in Ndjamena at 2.0 above the earth surface over the period from 1961 to 1990

Years	January	February	Marsh	April	My	June	July	August	September	October	November	December
1961	33,9	32,2	36,7	41,0	41,4	36,9	31,3	29,2	32,0	35,6	34,1	30,9
1962	30,9	34,4	39,6	40,3	40,1	35,9	34,1	29,8	32,2	35,7	37,1	34,0
1963	34,4	38,9	37,8	39,8	39,4	37,3	33,5	31,2	33,6	35,0	35,0	35,4
1964	33,6	34,4	39,9	41,1	40,2	37,0	32,0	29,4	32,1	35,3	35,1	34,3
1965	34,5	37,1	38,3	40,0	41,2	36,1	33,7	30,6	33,2	36,5	34,9	33,3
1966	33,7	34,1	39,0	39,9	37,8	35,0	34,7	31,9	33,6	37,4	37,6	34,1
1967	32,1	36,7	38,2	42,0	42,0	37,8	33,4	30,4	32,2	36,7	35,6	36,0
1968	32,7	36,4	39,7	39,9	39,1	34,0	31,8	32,2	34,3	37,6	36,9	35,1
1969	31,8	38,2	41,2	41,3	39,7	38,1	34,4	32,0	33,3	36,4	36,7	36,1
1970	34,0	35,7	38,7	41,6	40,7	39,0	34,0	30,6	32,0	36,8	35,9	33,3
1971	31,6	36,6	41,5	41,1	40,8	38,8	34,1	30,2	33,0	37,4	36,6	33,1
1972	32,6	36,1	40,0	41,0	39,4	37,6	35,1	32,4	35,1	36,7	34,9	35,0
1973	34,8	37,7	39,5	42,1	41,1	39,7	36,2	32,0	34,7	38,2	34,8	35,7
1974	30,9	35,3	38,5	41,7	39,6	38,2	31,6	31,0	33,2	37,7	36,3	31,4
1975	29,3	34,6	39,2	41,5	40,6	38,3	31,9	30,7	31,4	36,0	36,9	32,4
1976	32,8	37,1	37,7	40,4	39,9	36,5	32,4	32,2	33,4	36,2	35,3	31,0
1977	33,1	34,4	36,3	40,4	40	37,6	34,3	29,9	33,8	36	35	30,7
1978	32,2	35,8	38,2	41,2	40,2	38,1	33,3	31,2	33,3	36,8	35,7	32,2
1979	31,7	35,4	38,0	41,0	40,1	37,7	32,7	31,0	33,0	36,5	35,8	31,5
1980	31,8	35,5	37,9	40,9	40,2	37,6	32,9	31,0	33,0	36,3	35,7	31,6
1981	32,3	35,6	37,6	40,8	38,5	38,7	32,4	33,2	35,5	39,5	33,4	34,7
1982	32,8	33,9	38,6	42	40,7	38,3	35,1	32,1	35,1	37,8	36	34,6
1983	26,6	35,3	36,2	41	42,7	37	34,6	33,2	35,6	37,8	36	34,6
1984	30,8	34,7	40,1	40,9	39,8	38,7	35,8	35,9	35,6	38,3	35,9	31,4
1985	35	32,4	39,6	39,1	40,7	37,8	32,8	32,8	33,9	38	36,8	32
1986	32,4	37	40,2	42,4	40,9	38,9	32,4	31,3	32,5	37,4	36,4	31,1
1987	33,1	35,7	38,5	39,8	41,4	36,5	36,7	32,4	35,9	37,3	36,4	33,6
1988	31,9	34,7	39,6	42,2	40,7	37,4	33,2	30,3	31,5	35,7	36,1	32,1
1989	28,7	31	36,8	41,4	38,9	37,4	33	31,4	33,5	36,4	36,1	32
1990	34,1	32,2	36,2	42,6	40,8	39,8	32,3	33,4	36,4	38,6	38,6	36,4

The derivative of (2.2) with regard to each coefficient is given by the formula

$$\frac{\partial U}{\partial a_i} = \frac{\partial}{\partial a_i}\sum_{i=0}^{n}\left(a_n x_i^n + a_{n-1}x_i^{n-1} + a_{n-2}x_i^{n-2} + \cdots + a_1 x_i + a_0 - y_{exp,i}\right)^2, \tag{2.3}$$

i = 0,1,…,n.

Minimizing (2.3) to zero leads us to the searched system of equations to be solved for the coefficients of (2.1). Thus, we have:

$$\frac{\partial}{\partial a_i}\sum_{i=0}^{n}\left(a_n x_i^n + a_{n-1}x_i^{n-1} + a_{n-2}x_i^{n-2} + \cdots + a_1 x_i + a_0 - y_{exp,i}\right)^2 = 0, \tag{2.4}$$

i = 0,1,…,n.

Particularly for what concerns a linear function, (2.1) becomes

$$y = f(x) = a_1x + a_0. \tag{2.5}$$

Following the above procedure, (2.4) gives the next system of two equations to be solved for the coefficients a_0 and a_1 :

$$\begin{cases} a_1\sum_{i=0}^{n} x_i^2 + a_0\sum_{i=0}^{n} x_i = \sum_{i=0}^{n} x_i y_i \\ a_1\sum_{i=0}^{n} x_i + (\mathrm{n}+1)a_0 = \sum_{i=0}^{n} y_i \end{cases}$$

The obtained equations of regression should enable us to conclude whether parameter represented by function y increases or decreases during the considered period.

3. RESULTS AND ANALYSIS

Mathematical means over the whole period were calculated for each month and the results presented in Table 2.

From Table 2, highest values of the mathematical means were registered from March to June with maximum air temperatures between 37.6 and 41.0 °C. Lowest values, maximum air temperature between 31.5 and 36.9°C, were registered during the remaining months. This situation could be explained as follows.

From January to February and November to December, the atmospheric air circulating in the locality comes mostly from the desert of Sahara and is principally dry air. Moreover, this air is under Hadley cell, i.e. the vertical atmospheric circulation of the air is downward. Thus, no condensation of water vapor should be awaited. Instead, the air should need more heat for evaporation of residual water vapor which it still contains. This phenomenon obviously should lead to the decrease of the air temperature, particularly in December-January when the activities of the serial of Acores anticyclones in the area is intensive.

Starting from March, under the influence of the inter-tropical zone convergence, humid air from Atlantic Ocean penetrates into the locality. The upward convection of the atmospheric air leads to the condensation of water vapor in the air and the liberation of latent heat of condensation. Plus the quantity of water vapor in the air is consistent, plus the liberated heat is sufficient to cause the increase of the air temperature. Whence the high values of the mathematical means registered at that time. With the rainfall at the rainy season, the quantities of water vapor decrease in the air the air temperature decreases, too.

Thus, the time trend of the mathematical means of the monthly air maximum temperature should explained.

The quadratic standard deviations of these mathematical mean values of the monthly air maximum temperature in Ndjamena for the climatic period were all-over one order less the temperature. Moreover, they did not exceed 2.0°C. This indicates that monthly maximum air temperatures were scattered closer their corresponding mathematical mean values meaning that the time variability of this parameter was weak during the climatic period.

Table 2. Mathematical mean values, $\bar{\theta}$, of the monthly air maximum temperature in Ndjamena. s – corresponding quadratic standard deviations. Climatic period 1961-1990

Months	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
$\bar{\theta}$	32.3	35.3	38.6	41.0	40.3	37.6	33.5	31.5	33.6	36.9	35.9	33.3
s	1.9	1.8	1.4	0.9	1.0	1.3	1.4	1.4	1.4	1.1	1.0	1.8

Deviations, $\Delta\theta = \theta - \bar{\theta}$, of the monthly air maximum temperature from their mathematical means were calculated and the results presented in Table 3. To determine the functional relationship between the time in years and these deviations, i.e. $\Delta\theta = f(t)$, clouds of experimental points $M_i(t_i, \Delta\theta_i)$ were plotted in rectangular coordinates systems with t in the axis of abscissa and $\Delta\theta$ in the axis of ordinates, i=1, 2, …, 30. Note that t is an auxiliary variable for the time introduced to simplify the computational process; for year 1975, t = 0. Analyzing the configuration of the plotted clouds of points led to linear relationship between t and $\Delta\theta$, Figs. 1- 12. Thus, this relationship is represented by the function:

$$\Delta\theta(t) = at + b, \tag{3.1}$$

where a and b are to be found proceeding as indicated above.

January:

Proceeding as presented in the methodology, we obtain the decreasing linear formula

$$\Delta\theta(t) = -0.1t + 0.1. \tag{3.2}$$

Note that the negative coefficient of that regression line indicates that the maximum air temperature in Ndjamena was decreasing during the considered climatic period.

February:

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.1t - 0.0. \tag{3.3}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

Note that temperature is always given to 10^{-1} order, a precision which can appreciate a human eye when reading the indication of a thermometer. If computations of these coefficients are forwarded till order 10^{-2}, the last coefficient should be -0.04. Thus, (3.3) should become

$$\Delta\theta(t) = 0.1t - 0.04. \tag{3.3'}$$

March

Proceeding by analogy, we obtain the decreasing linear formula

$$\Delta\theta(t) = -0.04t + 0.1. \tag{3.4}$$

Note that the negative coefficient of that regression line indicates that the maximum air temperature in Ndjamena was decreasing during the considered climatic period.

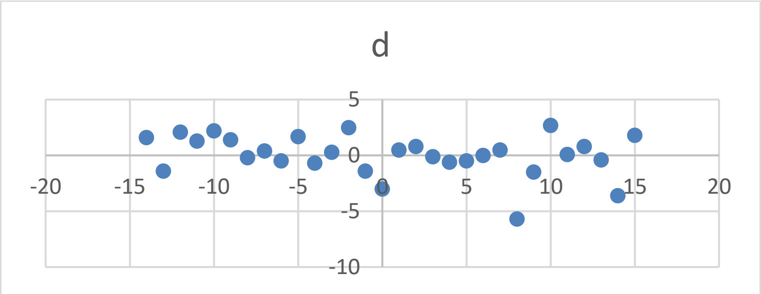

Fig. 1. Cloud of experimental points

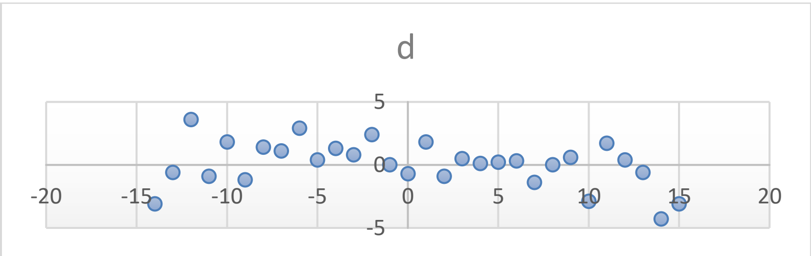

Fig. 2. The cloud of experimental points

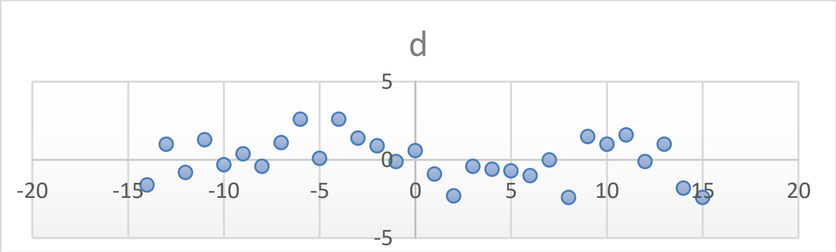

Fig. 3. The cloud of experimental points

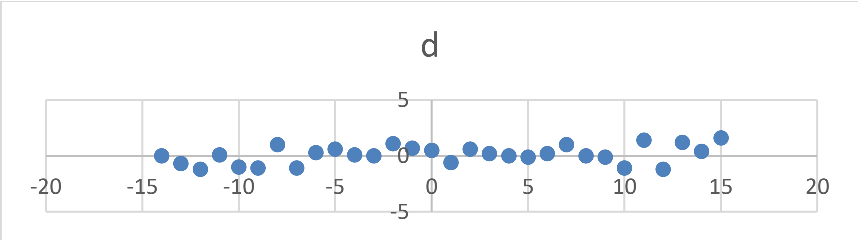

Fig. 4. The cloud of experimental points

April

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.03t + 0.1. \tag{3.5}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic peri.

May

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.03t + 0.4. \tag{3.6}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

June

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.1t + 0.0. \tag{3.7}$$

Computed constant term till 10^{-2} order is 0.04. Thus, (3.7) becomes

$$\Delta\theta(t) = 0.1t + 0.04. \tag{3.7'}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

July

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.02t + 0.01. \tag{3.8}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

August

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.1t + 0.0. \tag{3.9}$$

Computed constant term till 10^{-2} order is 0.02. Thus, (3.9) becomes

$$\Delta\theta(t) = 0.1t + 0.02. \tag{3.9'}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

Table 3. Monthly deviations, $\Delta\theta = \theta - \bar{\theta}$, of the monthly maximum air temperatures from their climatic monthly values over the period 1961-1990

Years	January	February	March	April	May	June	July	August	September	October	November	December
1961	1.6	-3.1	-1.6	0	1.1	-0.7	-2.2	-2.3	-1.6	-1.3	-1.8	-2.4
1962	-1.4	-0.6	1.0	-0.7	-0.2	-1.7	0.6	-1.7	-1.4	-1.2	1.2	0.7
1963	2.1	3.6	-0.8	-1.2	-0.9	-0.3	0	-0.3	0	-1.9	-0.9	2.1
1964	1.3	-0.9	1.3	0.1	-0.1	-0.6	-1.5	-2.1	-1.6	-1.6	-0.8	1.0
1965	2.2	-1.8	-0.3	-1.0	0.9	-1.6	0.2	0.9	-0.4	-0.4	1.0	0
1966	1.4	-1.2	0.4	-1.1	-2.5	-2.6	1.2	0.4	0	0.5	1.7	0.8
1967	0.2	1.4	-0.4	1.0	1.7	0.2	-0.1	-1.1	-1.7	-0.2	-0.3	2.7
1968	0.4	1.1	1.1	-1.1	-1.2	-3.6	-1.7	0.7	0.7	0.7	1.0	1.8
1969	-0.5	2.9	2.6	0.3	-0.6	0.5	0.9	0.5	-0.3	-0.5	0.8	2.8
1970	1.7	0.4	0.1	0.6	0.4	1.4	0.5	-0.9	-1.6	-0.3	0.0	0
1971	-0.7	1.3	2.6	0.1	0.5	1.2	0.6	1.3	-0.6	-0.5	0.7	-0.2
1972	0.3	0.8	1.4	0	-0.9	0.0	1.6	0.9	1.5	-0.2	-1.0	1.7
1973	2.5	2.4	0.9	1.1	0.8	2.1	2.7	0.5	1.1	1.3	-1.1	2.4
1974	-1.4	0	-0.1	0.7	-0.7	0.6	-1.9	-0.5	-0.4	0.8	0.4	-1.9
1975	-3.0	-0.7	0.6	0.5	0.3	0.7	-1.6	-0.8	-2.2	-0.9	1.0	-0.9
1976	0.5	1.8	-0.9	-0.6	-0.4	-1.1	-1.1	0.7	-0.2	-0.7	-0.6	-2.3
1977	0.8	-0.9	-2.3	0.6	-0.3	0.0	0.8	-1.6	0.2	-0.9	0.9	-2.6
1978	-0.1	0.5	-0.4	0.2	-0.1	0.5	-0.2	-0.3	-0.3	-0.1	-0.2	-1.1
1979	-0.6	0.1	0.6	0	-0.2	0.1	-0.8	-0.5	-0.6	-0.4	-0.1	-1.8
1980	0.5	0.2	-0.7	-0.1	-0.1	0	-0.6	-0.5	-0.6	-0.3	-0.2	-1.7
1981	0	0.3	-1.0	0.2	-1.8	1.1	-1.1	1.7	1.9	2.6	-2.6	1.4
1982	0.5	-1.4	0	1.0	0.4	0.7	1.6	0.6	1.5	0.9	0.1	1.3
1983	-5.7	0	-2.4	0	2.4	-0.6	1.1	1.7	2.0	0.9	0.1	1.3
1984	-1.5	0.6	1.5	-0.1	-0.5	1.1	2.3	4.4	2.0	1.4	0.0	-1.9
1985	2.7	-2.9	1.0	-1.1	0.4	0.2	-0.7	1.3	0.3	1.1	0.9	-1.3
1986	0.1	1.7	1.6	1.4	0.6	1.3	-1.1	-0.2	-1.1	0.5	0.5	-2.2
1987	0.8	0.4	-0.1	-1.2	1.1	-1.1	3.2	0.9	2.3	0.4	0.5	0.3
1988	-0.4	-0.6	1.0	1.2	0.4	-0.2	-0.3	-1.2	-2.1	-1.2	0.2	-1.2
1989	-3.6	-4.3	-1.8	0.4	1.4	-0.2	-0.5	-0.1	-0.1	-0.5	0.2	-1.3
1990	1.8	-3.1	-2.4	1.6	0.5	2.2	-1.2	1.9	2.8	1.7	2.7	3.1

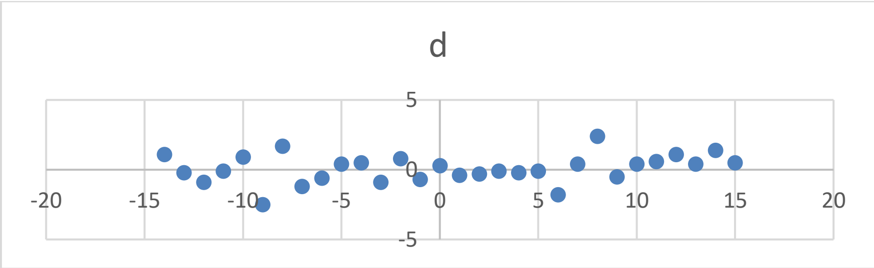

Fig. 5. The cloud of experimental points

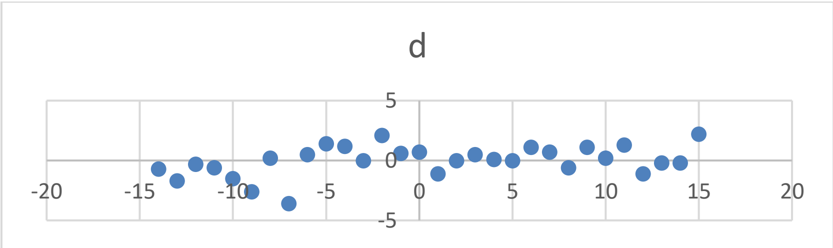

Fig. 6. The cloud of experimental points

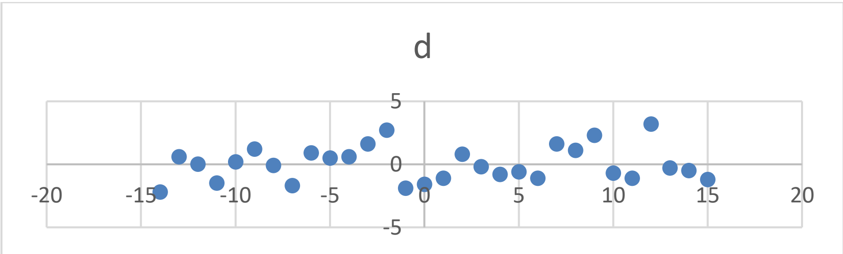

Fig. 7. The cloud of experimental points

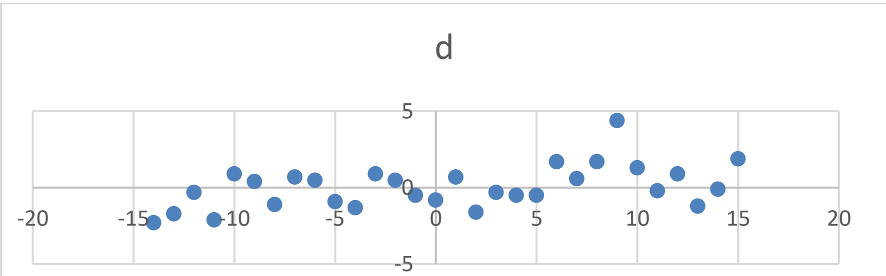

Fig. 8. The cloud of experimental points

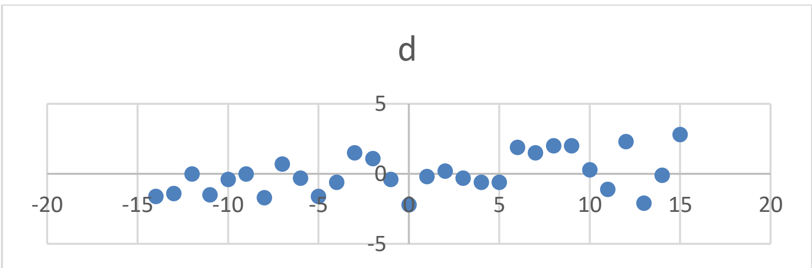

Fig. 9. The cloud of experimental points

September

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.1t - 0.0. \tag{3.10}$$

Computed constant term till 10^{-2} order is 0.02. Thus, (3.10) becomes

$$\Delta\theta(t) = 0.1t - 0.05. \tag{3.10'}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

October

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = 0.1t - 0.0. \tag{3.11}$$

Computed constant term till 10^{-2} order is 0.02. Thus, (3.10) becomes

$$\Delta\theta(t) = 0.1t - 0.04. \tag{3.11'}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

November

Proceeding by analogy, we obtain the null linear formula

$$\Delta\theta(t) = 0.0t + 0.0. \tag{3.12}$$

Computed coefficients till 10^{-2} order are a= 0.03 and b= 0.03. Thus, (3.12) becomes

$$\Delta\theta(t) = 0.03t + 0.03. \tag{3.12'}$$

Note that the positive coefficient of that regression line indicates that the maximum air temperature in Ndjamena was increasing during the considered climatic period.

December

Proceeding by analogy, we obtain the increasing linear formula

$$\Delta\theta(t) = -0.0t + 0.0. \tag{3.13}$$

Computed coefficients till 10^{-2} order are a= -0.05 and b= 0.05. Thus, (3.13) becomes

$$\Delta\theta(t) = -0.05t + 0.05. \tag{3.13'}$$

Note that the negative coefficient of that regression line indicates that the maximum air temperature in Ndjamena was decreasing during the considered climatic period.

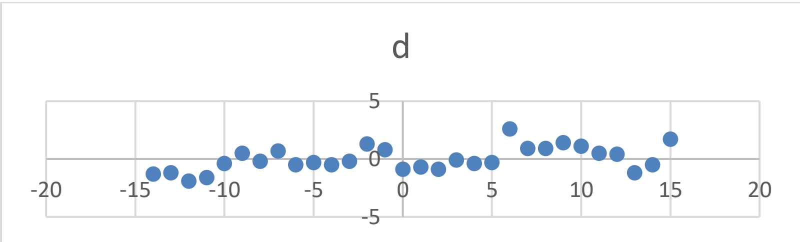

Fig. 10. The cloud of experimental points

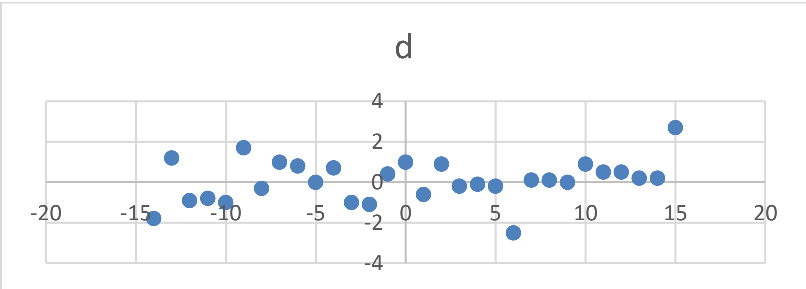

Fig. 11. The cloud of experimental points

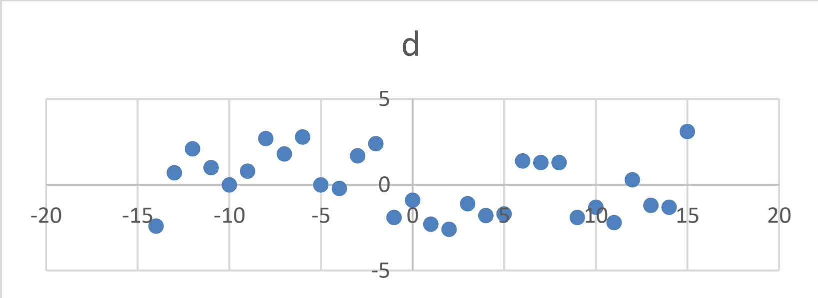

Fig. 12. The cloud of experimental points

A careful analysis of these graphs lead us to the next conclusion.

The values of these deviations were mostly included in the interval [-1.0°C;1.0°C] meaning that the monthly air maximum temperatures were scattered closer their corresponding mathematical mean values. This can be written by the inequality $|\Delta\theta(\mathrm{t})| \leq 1.0$°C. Let us recall that most values of the standard deviation were less or equal to 1.4°C. Thus, we may conclude that the results issued from modelling are closer to the observations. We should remark that just a few experimental points did not respect this tendency like the ones occurred in 1983 in January with $\Delta\theta$= -5.7°C, in 1961and 1989 with $\Delta\theta$ = -3.1 an -4.3°C in January and February, respectively, in 1967 in June with $\Delta\theta$= -3.6°C, in 1984 in August with $\Delta\theta$= 4.4°C and in 1987 in July with $\Delta\theta$ = 3.2°C. The lowest value of the deviation, -5.7°C, was registered in January 1983 and the highest: 4.4°C in August 1984. Some were around $\pm$ 2.5°C.

Annual mean values of the air maximum temperature with their corresponding standard deviations were computed for each year. The results are presented in Table 4 and their cloud of points plotted in Fig. 13.

Table 4 shows that these annual mean values varied from 34.6°C (in 1961) to 37.2°C (in 1973), giving an amplitude of variation of 2.6°C. During the first third sub-period, 1961-1970, this parameter oscillated frequently around 35.5°C. The values over 36.0°C were registered only during two years, 1967 with 36.1°C and 1969 with 36.6°C. During the second third sub-period, these annual mean values were at most 35.7°C except in 1971, 1972 and 1973 when they were above with 36.2, 36.3 and 37.2°C, respectively. During the last third sub-period, these annual mean values were frequently at least 35.5°C, mostly 36.0°C and above, meaning that this last third period was warmer than the two firsts. Moreover, the second third period was the coldest between the three thirds sub-periods of the considered climatic period.

Table 4. Annual mean values of the air maximum temperature in Ndjamena, $\overline{\theta}_{year}$ °C, and corresponding standard deviations, s °C, during the climatic period 1961-1990

Years	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Annual means	34.6	35.3	35.9	35.4	35.8	35.7	36.1	35.8	36.6	36.0
Standard deviations	3.9	3.5	2.7	3.6	3.1	2.5	3.7	2.9	3.3	3.5

1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
36.2	36.3	37.2	35.5	35.2	35.4	35.1	35.7	35.4	35.4
3.9	2.7	3.0	3.8	4.1	3.1	3.2	3.3	3.4	3.4

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
36.0	36.4	35.9	36.5	35.9	36.1	36.4	35.5	34.7	36.8
2.9	3.1	4.0	3.2	3.1	4.0	2.7	3.9	3.7	3.4

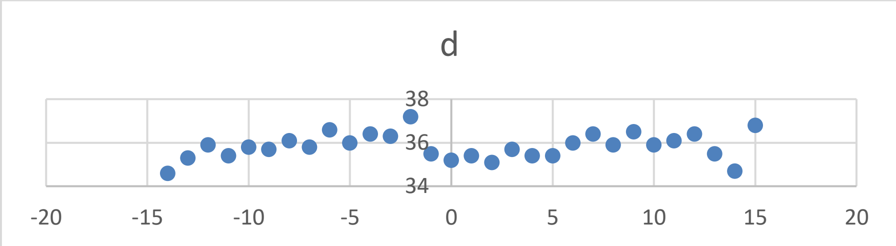

Fig. 13. The cloud of experimental points for annual means of the maximum air temperature

Taking into consideration the relative high values of the standard deviation, mostly above 3.9°C, we may conclude that the annual variability of this maximum air temperature should not be negligible in Ndjamena. Previous studies have revealed that this parameter with regard on the air temperature rarely exceeded 2.0°C, [4]. This high time variability should seriously impact some human activities in the locality.

Examining the configuration of the cloud of experimental points of the annual mean values of the maximum air temperature in Ndjamena, Fig. 13, leads to the conclusion that its time trend over the considered period can be modelled by a linear regression.

Proceeding as above, maintaining year 1975 for t = 0 and using the least squares method, leads to the analytic formula:

$$\bar{\theta}_{\text{year}} = 0.01t + 35.8. \qquad (3.14)$$

The low value of the coefficient of the line representing (3.14) confirms the already obtained above conclusions on the weak time variability of the maximum air temperature in Ndjamena during the period from 1961 to 1990, a tendency which seems to have no significant impact to the atmospheric thermal regime. The established models indicate that a slight increase of the maximum air temperature was occurring in Ndjamena during the whole climatic period.

At last, we should recall that according to the unpublished works of some agro-meteorologists led by Professor Y. Lomas in Bed Dagan, Israel, these low variations of the air temperature could seriously reduce the agricultural productivity in the locality. Thus, we must keep on controlling the thermal regime to avoid hunger disaster in our localities.

4. CONCLUSION AND RECOMMENDATIONS

This study has permitted to detect that the maximum air temperature was very slowly increasing in Ndjamena during the climatic period from 1961 to 1990. This low increase could not bring significant impact to the environment, except the plants and cultures whose yields should be affected, leading to the reduction probably considerable quantities of foods.

Therefore, to avoid situations which should lead populations to a disaster of hunger, between others, further similar investigations are strongly recommended. They should permit rulers to take on time appropriate measures and populations to have clearly ideas on the further development of the thermal regime in order to enable everybody to adopt adequate behavior.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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