Thermal effect and evolution in semi-arid climate: case of the Tata station from 1985 to 2016 (southern Morocco)

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Abstract
Under a very irregular semi-arid to desert climate, the city of Tata experiences a great temporal variability of rainfall and temperatures. In recent decades, it has recorded clear trends towards an increase in the number of warmer days and heat waves, especially during the often long summer period. The increase in temperatures has two important effects namely the impact of discomfort on the population and its activities on the one hand and on the other hand, increased evapotranspiration which will impact on the availability of water in the soil and will lead to water stress[6,7].

Hence the objective is to analyze the extremes of maximum temperatures covering the period (1985-2016), to determine maximum temperature trends and to extract the warm periods as well as calculate their evapotranspiration[1,9] which represent a significant portion of water loss in order to provide explanations for the real drought and heat waves experienced by the city.

Keywords: Temporal variability, summer period, temperature extremes, heat waves, evapotranspiration, drought.

Introduction

Morocco is experiencing in recent years episodes of heat and clear trends in temperature increases especially in the south of the country where temperature peaks are becoming more frequent, more intense especially in the summer period which extends from June to August Various studies and research have been conducted in this direction and these climatic changes and weather irregularities very frequent are of great concern[4,15].

The city of TATA like other cities in southern Morocco, is very vulnerable to climate change (figure1). Its climate is semi-arid to desert type and is characterized by a great interannual variability. It has experienced exceptional extreme events such as droughts, floods and heat waves[13]. The latter, in addition to other meteorological phenomena, induces severe droughts that will affect agricultural and livestock yields and generate more or less intense discomfort which is a source of concern for those in charge of health monitoring[12].

Within this framework, the objective of this study is to assess the trend of extreme temperatures recorded in the city of Tata and its suburbs, to calculate their evapotranspiration and analyse their evolution in order to understand these climatic disturbances and find explanations for these phenomena and try to put forward practical tools to adapt to them.

Material and Methods

Presentation of the study area: is an oasis city located in the South-East of Morocco, capital of the province of Tata since 1977 and urban municipality since 1992. Its territory is part of the region of Guelmim-Es-Smara. It is located on the national road no. 12 known as the "Road of the Oases" linking Sidi Ifni to Erfoud. It is part of a group of oases dotting the southern slopes of the Anti-Atlas and connected by the Wadi Draa. Three oases Tighremt, Indfiane and Afra are attached to the commune of Tata, their respective areas are 75, 40 and 85 ha. These three oases benefit from irrigation water from springs, khettaras and collective wells located along the Wadis of Tata and its tributary Wadi Ezouine[3,8].

Figures 2 and 3 show the locations of the urban commune and the surrounding oases. The commune of Tata is bound to the north by the communes of Tagmout and Tigzmirt. To the south, east and west, it is surrounded by the territory of Tigzmirt.

Research methodology: To carry out this study, we used a series of monthly data from 1985 to 2016 obtained from the Hydraulic Directorate of Rabat and the Sub-Massa-Darâa Watershed Agency of Agadir. The aim of this work is to study and analyse the evolution of the maximum temperature and the extreme heat recorded in the city of TATA and its suburbs and to calculate their aggressive evapotranspiration for the soil.

From the monthly records examined we deduce the annual temperatures according to the following formulas:

$$Ta = \Sigma Tm$$

where Ta=annual precipitation and Tm=monthly precipitation.

In the same order of design, we proceeded to cut the series into five-year time series in order to fully understand the temperature behaviour of the city under study. In order to calculate evapotranspiration, we used the Thornthwaite

method, which is used when temperature is the only climatic data available[16]. It expresses the potential evapotranspiration (PTE) by the following formula:

$$ETP = 16 \cdot \left(\frac{10 \cdot t}{I}\right)^{a} \cdot f(\varphi)$$

where t= Average air temperature under cover for the period considered, I= annual thermal index which is the sum of 12 monthly indices and $f(\varphi)$ is correction term depending on the theoretical duration of the insolation, the latitude and the month.

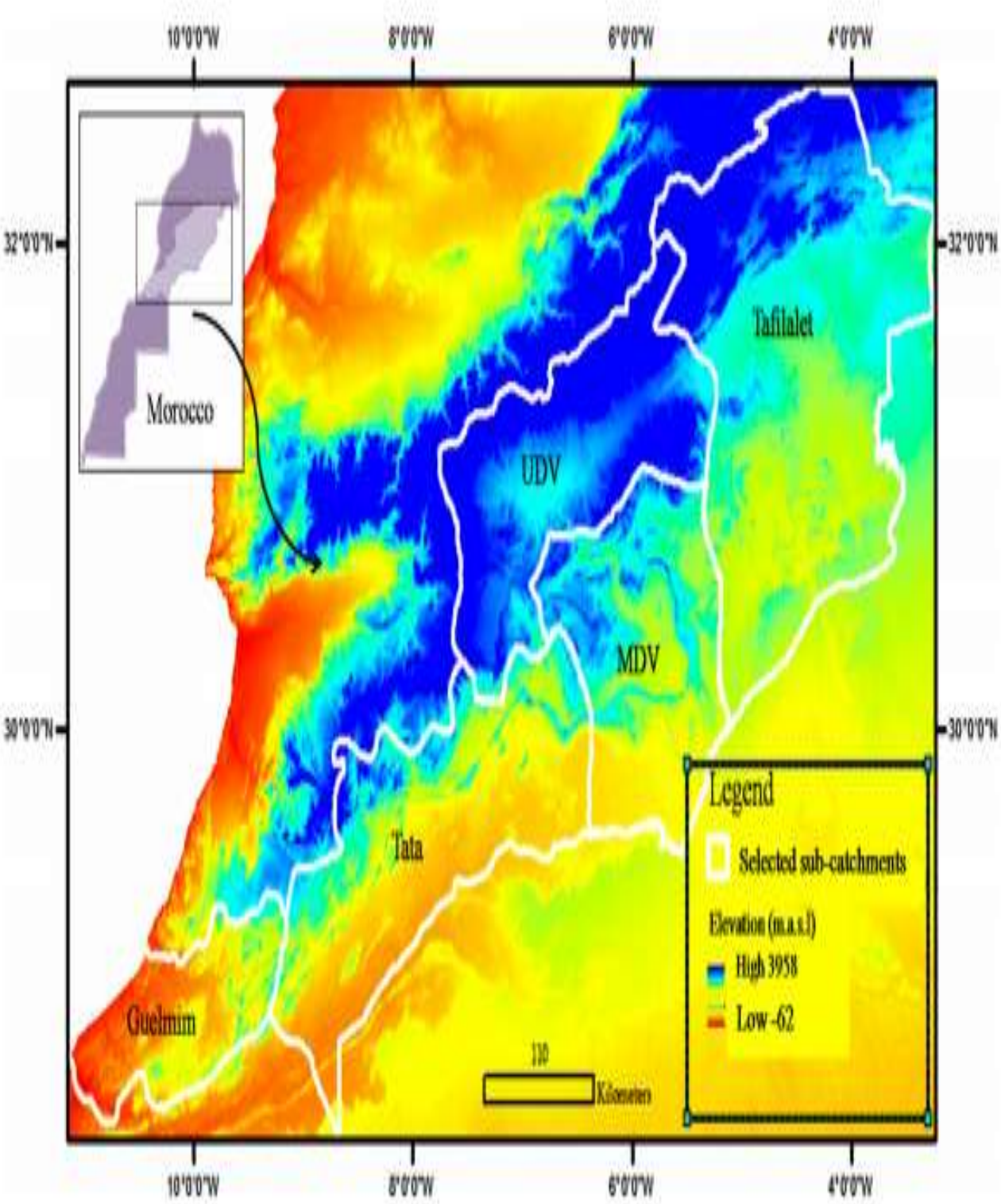

Figure 1: Pre-Sahara Southern Morocco: Oasis zone including the Guelmim, Tata, Zagora (MDV), Ouarzazate (UDV) and Errachidia (Tafilalet) sub-watersheds).[1]

Figure 2: Location of the municipality of Tata and the surrounding oases

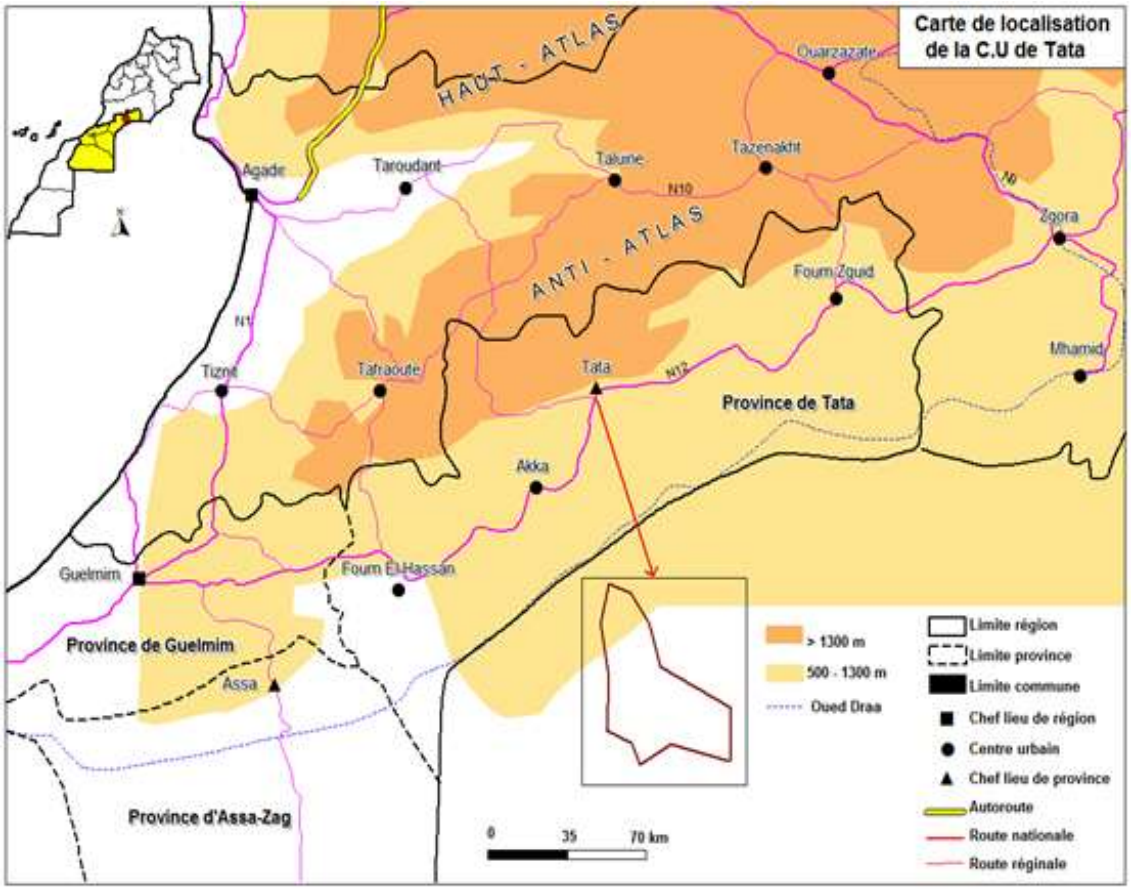

Figure 3: Location of the Tata UC within the territory of the Tata Province)[14]

Results and Discussion

The evolution of the annual average temperatures over the city of TATA and its suburbs is highly variable from one year to the next. But in general, the trend observed from 1985 to 2016 shows a clear warming and classifies this region of TATA as a geographical area very thermally hostile to humans and the ecosystem to maintain a modest sustainable development.

The three warmest years since 1985 are 1990, 2005, 2015 and 2016 with 34.4°C, 39.2°C and 39.3°C respectively (Figure 4). The processing of annual data has shown that the general trend is warming and figure 2 highlights this temperature increase. Overall, the five-year averages of annual temperatures between 1985 and 2016 indicate a trend of increasing and rising values (Figure 4). The observation of the evolution of the average temperatures obtained every five years confirms this annual temperature increase in Tata between 1985 and 2016. This is because we see that the averages recorded in 1985 and 2016 have increased despite the slight decrease observed during the period from 2005 to 2010 (Figure 5).

The evolution of the 5-year averages shows an increase in temperatures from 1985 to 2016 (Table 1). This temperature increase is not only observed on the scale of the analysis of interannual trends, but also on the scale of five-year averages. Extreme heat is most noticeable in summer. Figure 6 shows the degrees recorded over the period 1985-2016.

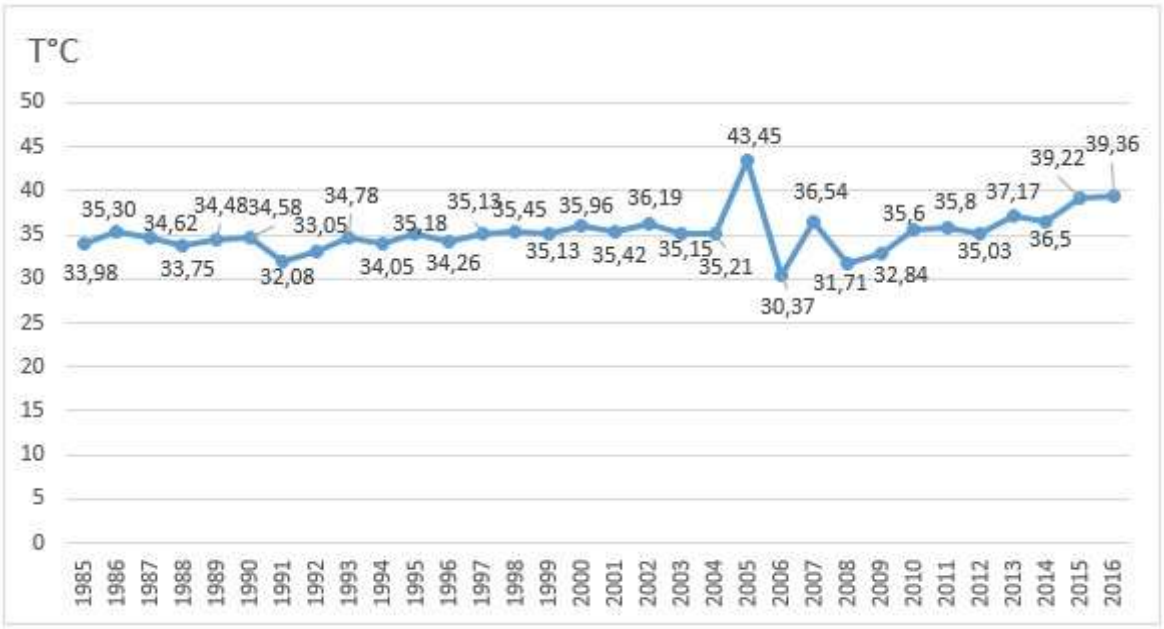

Figure 4: Annual temperatures at the Tata station

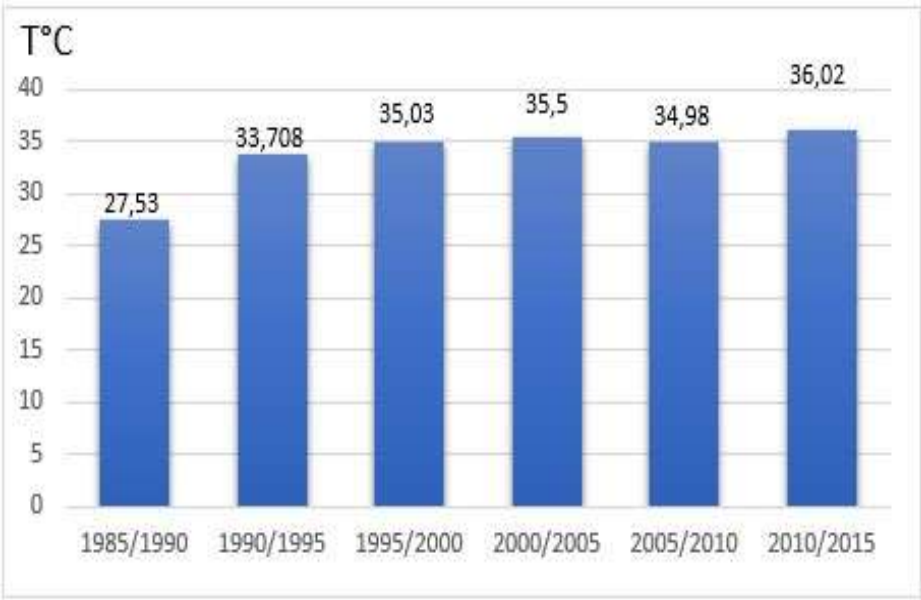

Figure 5: Evolution of five-year annual averages in Tata

The evolution of average maximum temperatures shows a clear warming for all summer months since 1985. All three months have average summer temperatures above 42°C; the average maximum temperature in the city with a trend that varies between +1 and +1.4°C per year. The city can record temperatures as high as 49°C. This was the case of August 2016. The three hottest summers since 1985 are 2012, 2015, 2016 with respectively 47°C; 48°C and 49°C mainly in the month of August (Figure 6).

Given the growth in degrees of the recorded temperatures and these extreme maximum values, the evaporative power of the city will increase, which will be directly felt in evapotranspiration and will influence the availability of water resources used especially in agriculture. Hence the interest in calculating evapotranspiration is an important parameter in the water balance[9,11]. The results obtained by the Thornthwaite method are shown in figures 7 and 8.

Table 1
Evolution of average temperatures (5 years) at TATA between 1985 and 2015.

Period	1985/1990	1990/1995	1995/2000	2000/2005	2005/2010	2010/2015
Average (T°C)	27,53	33,708	35,03	35,5	34,98	36,02

Figure 6: Mean summer temperature at Tata station

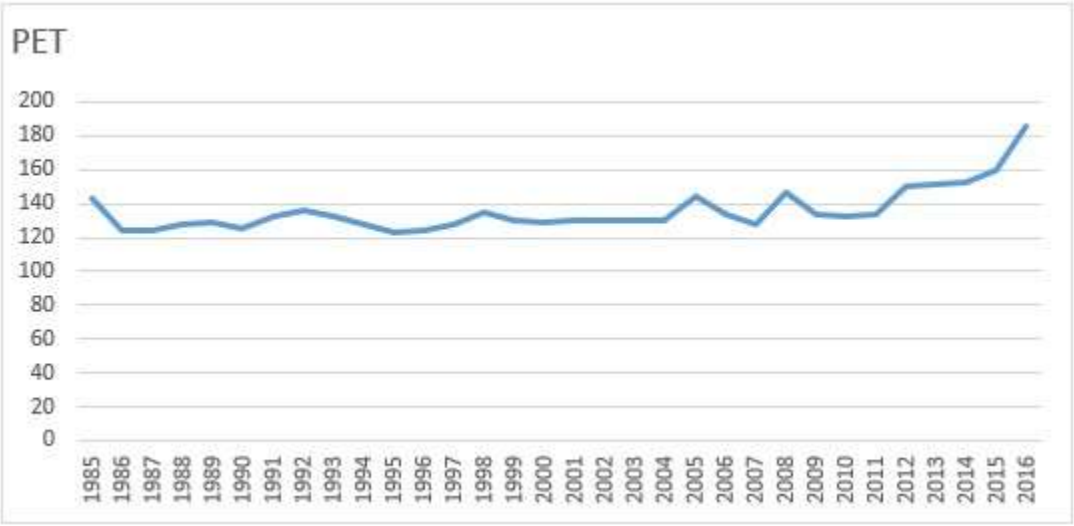

Figure 7: Annual evapotranspiration at the Tata station

Figure 8: Summer evapotranspiration at Tata Station

Table 2
Illustration of some cases of water drought between 1985 and 2016 in Tata.[5]

Année	Annual precipitation (mm)	Average (Mm)	Deficit (mm)	Rainfall index	Déficit%
1991/1992	11,70	30	18,30	0,39	-61%
2000/2001	7,50	30	22,50	0,25	-75%
2007/2008	2,40	30	27,60	0,08	-92%

Annual and summer evapotranspiration results show a trend increase during the three summer months. It reaches 185.57 mean annual evapotranspiration and 450.33 extreme values in August for the year 2016.

Rising temperatures, high evapotranspiration and changing rainfall patterns are vectorial parameters of change that are the causes of the water stress problems experienced by the city of TATA and its oasis suburbs. The table 2 represents a few years that have experienced real major sub-surface and sub-surface water deficits.

Conclusion

The results of this study highlighted the clear increase in temperatures, identifying both the highly warm periods with evapotranspiration rates, while indicating the general trend over the entire study period (1985-2016). The analysis carried out reflects a desert climate with unbearable heat and high evapotranspiration at the TATA city level.

The evolution of these extreme heat extremes is a big problem; it seems that the climatic trend in the TATA basin circumscribed in border reliefs is towards a clear warming and drying up. The results of this work are a wake-up call to decision-makers to define sustainable strategic adaptation policies, since these warming trends would still have hostile and harmful impacts on ecosystems.

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