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Trend Analysis of Potential Evapotranspiration Case of Chott-Meriem Region (The Sahel of Tunisia)

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***Abstract* — This study concerns the temporal trends of the evapotranspiration (ETo) and the climatic parameters that influence it, using the Penman – Montheith methodology described in the FAO Irrigation and Drainage Paper N°56.**

Temporal trend of the climatic parameters and the reference evapotranspiration of 34 years, have been analyzed using the Mann-Kendall trend test for the Chott-Meriem station in the coastal region of Tunisia. The sensitivity of ETo has been studied in term of change of most involved climatic parameters. The results show that maximum and minimum temperature doesn't evolve similarly. A Significant temperature trend, was detected during spring and summer period (hot season), especially for maximum temperature. A highly significant trend for the air vapour deficit was detected which appear especially from May to June. The wind speed shows a significant decrease trend during the year. The sensitivity analysis test showed that, the most influent parameter on ETo are respectively, net solar radiation, the actual vapour pressure, the long wave radiation, and the maximum temperature.

***Keywords* — Reference Evapotranspiration, Climate Change, Trend, Tunisia.**

I. Introduction

The Intergovernmental Panel on Climate Change (IPCC) reported since 2007 that climate change is occurring worldwide, and they confirm it in their fifth report [1] as global warming is unequivocal, its effects are already being felt in all environments and sectors (agriculture, health, land and ocean ecosystems, water...) on all continents and oceans, from small islands to large continents. Although climate change occurred on a global scale, its impacts often vary from region to other [2]-[3]. However, the countries that will be severely affected by global warming are those which already suffers from hard climatic condition, as aridity [4], in addition to a low annual GDP[5]-[6] so the countries whose economic development options are limited and based on the exploitation of water, priority sector to promote the agriculture and agro-industry to meet the needs of their people and earn foreign exchange revenue to finance economic development [7].

It is expected that changes in climatic variables will affect precipitation and evaporation therefore, causes changes in the hydrological cycle [8]-[9]. Evapotranspiration is considered the most significant indicator for climate change and the water cycle as it is the only connection linking the water balance and the land surface energy balance [10]-[11]-[12]. Indeed, it's a key element in the hydrological cycle, and plays an important role in the estimation of crop growth, water demand and irrigation management. Consequently, estimation of ETo changes, are of great importance for the planning and management of water resources and agricultural production.

Relating to global warming the issue of spatial and temporal changes in climatic variables and evapotranspiration is a matter of much debate, and studies are increasingly going on worldwide [13]-[14]-[15]-[16]-[17]-[18]-[19]-[20]-[21]-[22].

Despite that climate warming is almost confirmed worldwide, the evapotranspiration trend is not obvious and may increase or decrease depending on climatic conditions and regions [23]. The studies of [24]-[25]-[26], indicate that the evapotranspiration trend is not determined only by temperature. Many studies [27]-[28]-[29], have shown a decrease in the evapotranspiration trend over the past decades in many places of the world, however others has reported the opposite phenomenon [27]-[20]-[30]-[31]-[32].

As the most Mediterranean countries, Tunisia already suffers from weather variability in addition to the problem of water scarcity. In fact, Arid to semi arid climate represent 75% of the total area, what makes agriculture and water sector the most vulnerable to the predicted climate change. The water balance (rainfall-evaporation) shows that the most part of the country suffers from water deficit.

Under such fragile conditions, a marginal increase in water demand due to global warming would put a tremendous pressure on existing water resources. The most important consequence is that the country, that already suffer from water scarcity will not have enough water to maintain the same level of agricultural production from irrigation, and to satisfy demand in drinking, industrial water, and ecosystems necessities. The world bank [33] ranked Tunisia as a stressed water country that will be in absolute rarity of water resources by 2025. The expected climatic change, population increase, urbanization and industrial development as well as irrigation intensification will make the water management a real headache in the future.

In the aim to assess and quantify the impacts of climate changes on water availability and crop water requirement in the future and in this context we tried to study the trend of climatic parameters, and their effect on the reference evapotranspiration for the sahel region of Tunisia, one of most vulnerable region of the country concerning water resources and agriculture sector.

II. Materials and Methods

A. Characteristics of Study Area

The center region of Tunisia is one of vulnerable region of the country, because of its high climatic variability and its mainly rainfed agriculture. In this region, water deficit and drought represent a permanent risk for rainfed agriculture. The temperatures are moderate, very hot conditions are frequent and may occur from May to September. The study has concerned the site that represent the coastal centre of Tunisia, given the lack of long-term climatic data for most stations, we have chosen the region of Chott - Meriem (35°55N lat, 10° 34 E long,15m alt),the site that represents the more available data. Daily observed maximum and minimum air temperature, rainfall, wind speed measured at 2m height, relative humidity and daily sunshine duration, data of 34 years (1973-2007) have been used.

B. Reference Evapotranspiration

The Penman-Monteith method [34], known as the most reliable method for various climatic conditions, is used to calculate the ETo. This method integrates not only temperature but also radiometric and aerodynamic variables [34]-[35] and can reflect the combined effects of various meteorological variables. The FAO Penman-Monteith equation requires data on, mean daily air temperature, relative humidity sunshine duration and wind speed (at 2 m height) given as:

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \dfrac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

Where **ETo** is the reference evapotranspiration [mm day−1], **Rn** is the net radiation at the crop surface [MJm^{-2} day^{-1}], **G** is the soil heat flux density [MJm^{-2} day^{-1}], **T**is the mean daily temperature at 2m height [◦C], u_2 is the wind speed at 2m height [m s^{-1}], e_s is the saturation vapour pressure [kPa], e_a is the actual vapour pressure [kpa], $e_s - e_a$is the saturation vapour pressure deficit [kPa], Δ is the slope of vapour pressure curve [kPa◦C^{-1}], γ is the psychrometric constant [kPa◦C^{-1}].

C. Trend analysis

The Mann-Kendall trend test [36]-[37]which is highly recommended for general use by the World Meteorological Organization [38] was used to determine the trends for the reference evapotranspiration (ETo) as well as dependent climatic parameters.

The MAKESENS (Mann-Kendall test for trend and Sen's slope estimates) developed by [39], for detecting and estimating trend in time series of annual values and monthly values, have been used to study the trend of climatic parameters and reference evapotranspiration (ETo).

The Mann-Kendall test is applied in case when data values x_i of a time series can be assumed to obey the model:

$$x_i = f(t_i) + \varepsilon_i \quad (2)$$

Where f(t) is a continuous monotonic increasing or decreasing function of time, ε_I is a residual that can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time.

The statistical test is used to test the null hypothesis, H_o that the data is randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test MAKESENS exploits both S statistics given in [40] and the normal approximation Z statistics. For time series with less than 10 data points the S test is used, and for time series with10 or more data points the normal approximation is used. The S Statistic test is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (3)$$

Where x_j et x_k are the annual values in years *j* and *K*, *j>k* respectively, and:

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

D. Sensitivity Analysis

A sensitivity analysis of the reference evapotranspiration (ETo) to meteorological variables was performed using the Palisade precision tree (vers1.0) tools for Microsoft excel.

Both one way and two-way sensitivity analysis were used. The One-way sensitivity analysis studies the effect of a single variable on the expected value of a model, and the two-way sensitivity analysis studies the impact of two variables on a decision model.

III. Results and Discussions

A. Rainfall

The rainfall parameters didn't present any temporal trend at annual scale(fig1), however at monthly scale a significant increasing trend (α =0.05) have been noticed for the month of September (table II).

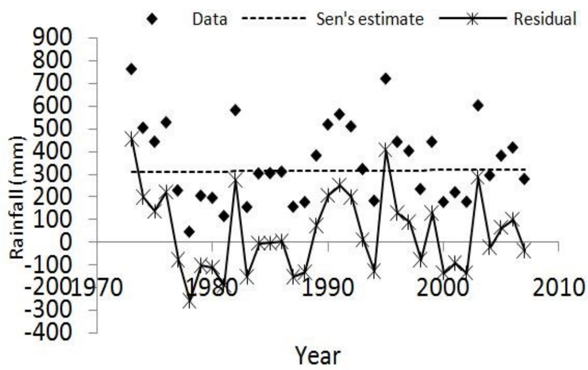

Fig. 1. Mann Kendall trend test for average annual rainfall during the period 1973-2007

B. Evapotranspiration Trend

In the aim of determining to trend of the evapotranspiration (ETo), mean yearly and mean monthly values were deduced from the daily data. The Mann-kendall trend test, used to determine the annual trends of ETo, shows that there is no statistically significant trend of ETo (Fig 2)

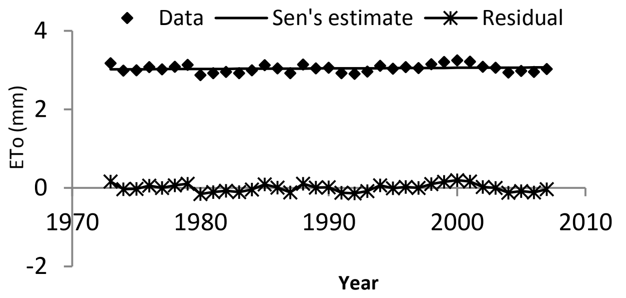

Fig. 2. Trends of average annual ETo using Penman-Monteith FAO-56 equation during the period 1973–2007

As we didn't obtain a clear trend of the reference evapotranspiration (ETo), unlike those shown in several previous studies [27]-[28]-[29]-[24]-[20]-[30]-[41]-[32].We tried to go deeply and understand more the cause of this result. Knowing that the Penman-Monteith ETo is the combination of the aerodynamic and radiation terms, we tried to study the trend of each term alone.

The reference evapotranspiration equation (1) [34], can thus be writing as the sum oftwo parts (5), the radiation term (6) and aerodynamic term (7) [42].

$$ETo = ETorad + EToaero \qquad (5)$$

With

$$ETorad = \frac{0.408\Delta(Rn - G)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (6)$$

$$EToaero = \frac{\gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (7)$$

The temporal study of each single part, shows a clear and statistically significant trend but in opposite way for the two terms. Indeed we recorded an increase trend of the radiation term ETrad (fig3) against a decreasing trend of aerodynamic term EToaero (fig4).

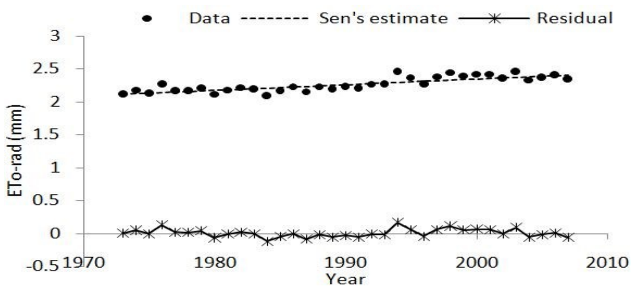

Fig. 3. Trends of the radiation term (ETo rad)

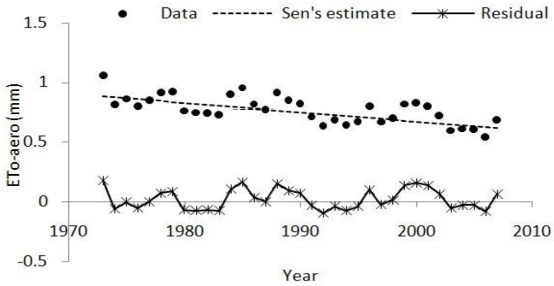

Fig. 4. Trend of the aerodynamic term (ETo aero)

These opposite trends, of the two parts that constitute thePenman - Monteith FAO-56 equationof the reference evapotranspiration explain why we haven't detect a significant trend of ETo during the previous study.

In second step, we tried to have more details on this trend, so we studied the evolution of the different climate parameters involved in ETo calculation as explained in [34].

C. The trend of the Climatic Parameters

The Mann-Kendall test was applied for climatic parameters involved in ETo calculation both at yearly and seasonal scale.

At yearly scale Results showed a height significant trend (0.001 level of significance) of maximum temperature, wind speed and the vapour pressure deficit (VPD) and also respectively with less degree of signification, the minimum temperature, mean relative humidity (HR), the Sunshine hour, the solar radiation (Rs), the net shortwave radiation (Rns), and the net long-wave radiation (Rnl) (Table I).

For seasonal scale when applying the Mann-Kendall trend test for the monthly maximum temperature we noticed that, there is a height significant increasing trend (α=0.001) from April to June (table II). According to this analysis the autumn and the summer, are becoming warmer, on the other hand there is no trend for the winter period. The minimum temperature present the same trend but not as the same level of signification as the maximum temperature (table II). In addition the maximum temperature increase is more important, especially during the warm period.

For the two parameters that influence the flux of the water through the crop, as known VPD (vapour pressure deficit) and Rn (net radiation), we noticed a height significance increasing trend of the vapour pressure deficit, from May to June period (table II) and two opposite trend period for the Rn (increasing trend from January to May and decreasing trend from September to October).

The wind speed trend showed a general decrease throughout the year, and this trend is highly significant (α=0.001) from March to October (table II).

Even if similar trend was cited by [24]-[43]-[44], linking this downward trend of the wind speed to climate change phenomenon must be considered with more delicacy; because such change in wind speed can also be the result of any environmental changes in the measuring station vicinity, such as the trees growth and the buildings

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rising.

D. *Sensitivity Analysis*

In the aim to study which climatic variable affect most the reference evapotranspiration (ETo), we applied a sensitivity analyses on the most involved climatic variables in the evapotranspiration calculation. The mean of the 34 years daily values of the climatic parameters was used with the [-20% to +20%] variation ranges.

The results represented in thefig5shows that the most influential climatic data on the reference evapotranspiration (ETo) are the solar net radiation (Rns), followed by the actual vapour pressure, the net long wave radiation(Rnl) and the maximum temperature (Tmax). If use only the measured meteorological parameters needed as input in the ETo calculation in Penman - Montheith method, we noticed that the relative humidity (HR), maximum temperature (Tmax) and the wind speed (U_2) present the most influential factors (fig 6).

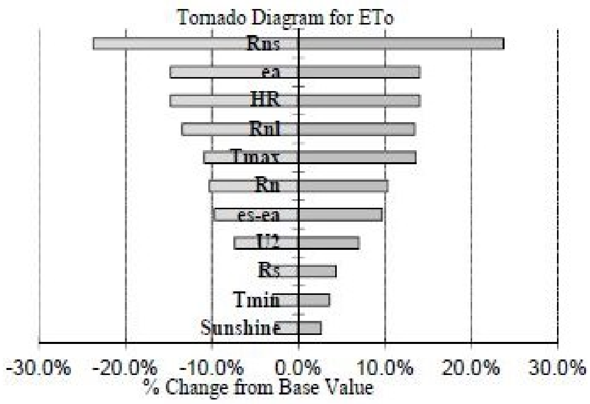

Fig. 5. Sensitivity analysis and classification by impact, of climatic parameters variation on reference evapotranspiration (Rns: net solar radiation, ea: actual vapour pressure, Rnl:net long wave radiation, Tmax: maximum temperature, Rn: net radiation, es-sa: saturation vapour pressure deficit, U2:wend speed, Rs:solar radiation, Tmin: minimum Temperature, Sunshine: duration of Sunshine).

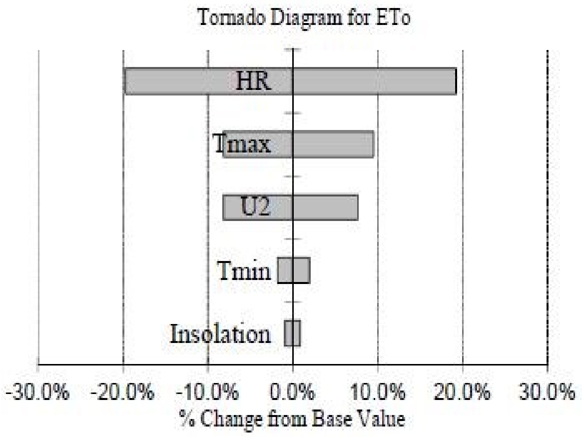

Fig6: The sensitivity analysis and classification by impact on reference evapotranspiration for major metrological variables measured in the Chott - Meriem region (HR: relative humidity, Tmax: maximum temperature, U2: wend speed, Tmin: minimum temperature, insolation: duration of sunshine).

Table I: Recap of Mann kendall test applied to ETo and climatic variables at yearly scale.

	First year	Last Year	n	Test Z	Significance
Tmin	1973	2007	35	2.66986923	**
Tmax	1973	2007	35	5.04201684	***
HR	1973	2007	35	-2.54282571	*
U2	1973	2007	35	-5.83737725	***
ea	1973	2007	35	0.88048879	
es-ea	1973	2007	35	3.77758093	***
Sunshine	1973	2007	35	1.72005078	+
Rs	1973	2007	35	1.69162019	+
Rs/Rso	1973	2007	35	1.80534256	+
Rns	1973	2007	35	1.69162019	+
Rnl	1973	2007	35	1.90299189	+
Rn	1973	2007	35	1.27812888	
ETo	1973	2007	35	0.82368306	
ETorad	1973	2007	35	5.1409184	***
EToaero	1973	2007	35	-4.06160957	***
Rainfall	1973	2007	35	0.28402864	

****α =0.001level of significance/** α =0.01level of significance / * α =0.05 level of significance / + α =0.1 level of significance*

Tmin: minimum Temperature, Tmax: maximum temperature, HR: mean relative humidity, U2: wend speed, es-ea: actual vapour pressure, sunshine: relative sunshine duration, Rs: solar radiation, Rs/Rso: relative shortwave radiation, Rns: net solar radiation, Rnl: net long wave radiation, Rn: net radiation, ETo: reference evapotranspiration, ETorad: radiation term of ETo, EToaero: aerodynamic term of ETo.

Table II: Temporal trend of climatic parameters

	Dec	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov
Tmin				*	**	**	**		*			
Tmax			+	**	***	***	***	*	**		**	
ea				*	**	*						
U2	*	**	**	***	***	***	***	***	***	***	***	*
Rns	*	+		+								
Rnl	**	*										
es-ea					+	***	***	*	**		*	*
Rainfall										*		

**** α =0.001level of significance / ** α =0.01level of significance / * α =0.05 level of significance / + α =0.1 level of significance*

Tmin: minimum Temperature, Tmax: maximum temperature, ea: actual vapour pressure,U2: wend speed, Rns: net solar radiation, Rnl: net long wave radiation, es-sa: saturation vapour pressure deficit.

IV. Conclusion

From the above results the following conclusion may be drawn:

When applying the Mann Kendall test to the Penman–Montheith ETo does not disclose any significant trend.

As the ETo equation is the sum of two terms, known as radiation and aerodynamics. The temporal study of each part alone showed a significant trend, respectively, increasing and decreasing of ETrad and ETaero. This opposite trend of the two term explained the cancelled trend of their sum ETo.

The trends of all climatic data on which the reference evapotranspiration depends, were analyzed. The study showed a significant increasing temperature trend mainly during spring and summer periods (hot season), especially for maximum temperatures. In addition, maximum and minimum temperature does not evolve similarly.

This phenomenon was also reported in the third IPCC report [5] as well as by some authors such as, [45], [46] and [47].

Indeed, maximum temperature trend is more important and more spreading.

A significant downward trend of the wind speed was recorded. However, despite that similar results have been mentioned by several authors in different studied places, this result must be considered with much precaution, because such change can be result of environment changes around the measure station.

A new micrometeorological stationwas installed to compare the values recorded with the old one and consequently understand the cause of the downward trend phenomenon. A long measurement period is necessary, so the results will be published shortly.

We noticed also a significant decreasing trend of relative humidity (HR) with an increase in the actual vapour presser (ea). As a result, a higher significant trend for the vapour pressure deficit (VPD) that occurs essentially from May to June. The problem is that the region already suffer from water shortage and such increase in air vapour deficit will surely boost the crop water stress in the future.

According to sensitivity analysis, the most important climatic parameters that affect the reference evapotranspiration and the crop water requirement are mainly the net shortwave radiation, the actual vapour pressure, the long wave radiation and the maximum temperature. The actual vapour pressure and the net long wave radiation affect the reference evapotranspiration in opposite way of their trend.

The regional study is important for future climatic scenarios and the sustainable plan development for the country. The temporal trend analysis of the climatic parameters is a step that gave us the possibility to understand how the climate is changing and this will be used to develop future scenarios of reference evapotranspiration (ETo) and crop water requirement (ETc), under climate change condition at studied region.

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