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title: **Evaluation of evapotranspiration variation in the Draa basin using statistical and empirical methods (South-Eastern Morocco)**

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ABSTRACT

In arid and semi arid environment, water is an important limiting resource not only for its scarcity, but also its intermittency and unpredictable presence. In the Draa basin; water resources knows a decrease from the upstream towards the downstream which is translated by a decline of precipitation ratio (A mean of 270 mm in Agouim and 66.5 mm in Zagora) and an increase of evaporation (255 mm in Agouim and 360 mm in Zagora) and temperatures mean. Precipitation and evapotranspiration are the most important variables to diagnose the climate changes and their effects on the environment. The analysis of these climatic parameters seems important to understand and forecast the resources instability. The methodology adapted in this work is focused on the statistical analysis of evaporation time series. These analyses include the detection of trends via Mann Kendall test, the detection of Mean series change using a cumulative deviation and Student's t-test, and the cross correlation test to correlate the rainfall to evaporation time series.This study was conducted for 7 stations where six are located in the high Draa basin (Mansour-Eddahbi, Ait Mouted, Iffre, Agouim, Agouilal, Assaka) and Zagora station situated in the Middle Draa at a elevation of 707 m.a.s.l. The analysis outcomes reveal the existence of variations and change within the series; however, the size of this change seems difficult to prove.

INTRODUCTION

The Draa catchment climate is arid to semi arid; it is characterized by low precipitation rates which decrease with the elevation showing inter and intra annual variabilities. The evaporative power in the region knows a very remarkable increase because of the temperature degree which can reach up to 56°c as maximal extreme value in Tagounite station. The evapotranspiration is an important parameter of the water balance which influences the availability of water resources, particularly for the agriculture and which constitute a very rarely measured object. In the region of study, the quantification of the evaporated proportions is very difficult; In the Middle Draa aquifers; the groundwater level knows an important fluctuations, and the evaporation by capillarity process caused the lowering of water table. The global climate change can cause a variation in the evolution of the meteorological factors. The study main is to analyze the time series of the parameter of evaporation using parametrical and non parametrical tests for given periods. The data used comes from the principal hydro-equipped stations and they were chosen as the records spreads out over important periods without gaps.

SITUATION OF STUDY CATCHMENT

The high and middle Draa catchments are situated in the southeast of Morocco, it extends over a surface of 42000 km² and it is limited to the North by the south side of the High Atlas. This region is characterized by the climate aridity and water resources scarcity. The precipitations in this area constitute a main element of dam and aquifers refill (Fig. 1).

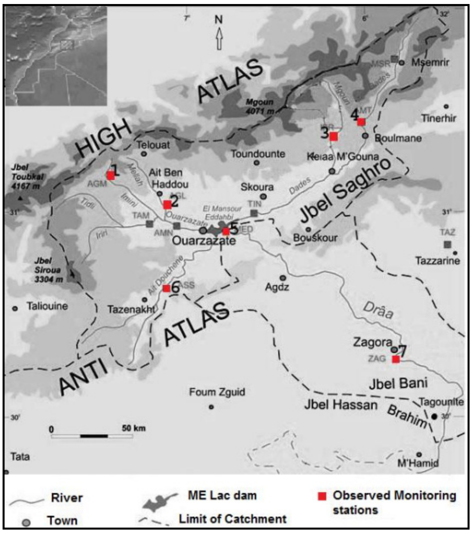

Figure 1. Situation of study area.

COMPARISON OF POTENTIAL EVAPOTRANSPIRATION TO LAKE EVAPORATION

Although the computation methods of evapotranspiration parameter are multiple; however, the evaluation of the real evaporated quantities values remains very difficult because of the interaction of several climatical and anthropological factors. The estimation of the potential evapotranspiration (ETP) in this work was based on the Thornthwaite empirical method which depends only on the effect of the climatic conditions and ignores that of the vegetation. This hypothesis is not precise, but the method of Thornthwaite was widely applied in hydrology, because of its low data requirements (only average monthly temperature data). The formula for the calculation of potential evapotranspiration is as follows.

$$E = 16C\,(10T_m/I)^{a}$$

E stands for potential evapotranspiration (in mm), ***C*** is the daylight coefficient, T_m is the mean monthly temperature (°C), ***a*** is an exponent derived from the heat index (***I***) and they were expressed by the following equations:

$$a = (67.5\times10^{-8}I^3)-(77.1\times10^{-6}I^2) + (0.0179I) +(0.492)$$

$$I = \Sigma\,(T_m/5)^{1.51}$$

The results obtained by this method were correlated to the lake evaporation which derives from the pan evaporation (class A) records. Pan evaporation is used to estimate the evaporation from lakes. There is a correlation between lake evaporation and pan evaporation. Evaporation from a natural body of water is usually at a lower rate because the body of water does not have metal sides that get hot with the sun. Most textbooks suggest multiplying the pan evaporation by 0.75 coefficient to correct this difference. The values of ETP and lake evaporation show increases for June, July and August (Figure 2). The important peaks are registered in July when the relative humidity shows the lowest values.

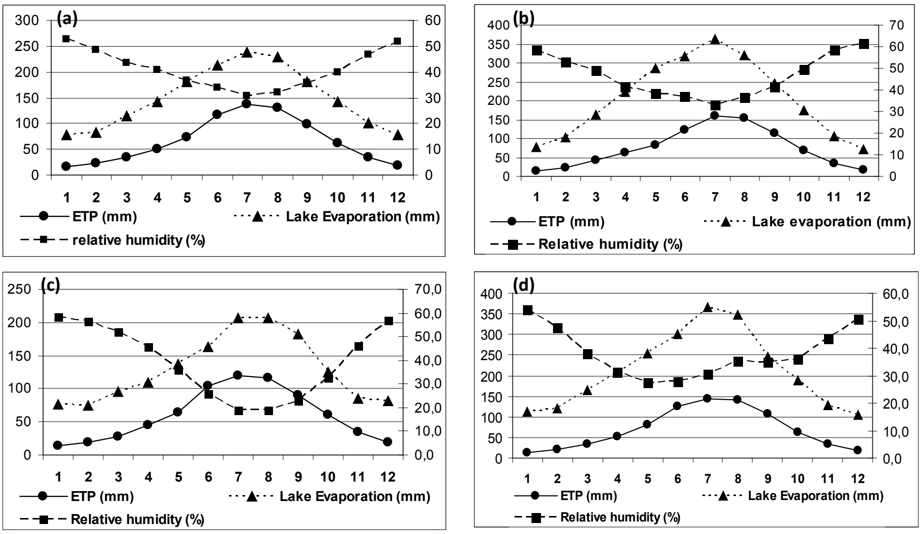

Figure 2. Diagrams representing mean monthly values of ETP, lake evaporation and relative humidity. (a) Iffre (b) Mansour-Eddahbi (c) Agouim (d) Ait Mouted.

The comparison shows a big similarity in the temporal variables evolution. As the volumes of waters transpired compared to those evaporated from lakes (Mansour-Eddahbi dam), channels are not important; the analysis of the volume recorded in hydrometric stations constituted the main objective of this study.

DETECTION OF EVAPORATION TRENDS: MANN KENDALL TEST

The evapotranspiration is a very important constituent in the water balance and the influence on the availability in water; essentially for the agriculture. The identification of evapotranspiration series trends in respond to climate change allows the estimation of the potential impact of climate change on the evapotranspiration. There are many parametric and non-parametric methods that have been applied for detection of trends (Zhang et al., 2006). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. On the other hand, non-parametric trend tests only require the data be independent and can tolerate outliers in the data. One of the widely used non-parametric tests for detecting a trend in hydro-climatic time series is the Mann–Kendall test (Hirsch et al., 1982; van Belle and Hughes, 1984; Zetterqvist, 1991; Zhang et al., 2001; Burn and Elnur, 2002; Yue et al., 2002; Yue and Wang, 2002; Yue and Pilon, 2004; Burn et al., 2004; Zhang et al., 2005; Arora et al., 2005; Aziz and Burn, 2006; Gemmer et al., 2004; Zhang et al., 2006; Zhu and Day, 2005). The methodology adapted in this current study is based on the *Man Kendall test* associated with the technique of bootstrap. The trends analysis was made on 4 hydro-meteorological sites located on the high and middle Draa catchments. The values ***n*** of the temporal series (X_1, X_2, X_3, X_n) are replaced by their relative ranks (R_1, R_2, R_3, R_n). The statistical test is:

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^{n} \mathrm{sgn}(R_j - R_i \right]$$

Where:

$\mathrm{sgn}(x) = 1$ for (x>0)

$\mathrm{sgn}(x) = 0$ for (x=0)

$\mathrm{sgn}(x) = -1$ for (x<0)

If the null hypothesis ***H₀*** is true, then ***S*** is normally distributed with: $\mu = 0$ and $\sigma = n(n-1)(2n+5)/18$. The Z test is thus: $Z = |S|/\sigma^{0.5}$. The positive value of ***S*** indicates an increase of the trend and vice versa.

The techniques of bootstrap are modern statistical methods of inference which demand an extensive computing calculation. The objective is to know some indications on a statistics: naturally, its estimation, but also the dispersion (variance, standard deviation), the confidence levels, and the hypothesis test. This method is based on simulations, as the methods of Monte Carlo, Bayesian method, the algorithm of Metropolis-Hastings, with the difference that the bootstrap does not require additional information and depends only to the available data in the sample. Generally, the bootstrap is based on «new samples» obtained by resampling from the initial sample. In resampling analysis, the original time series is resampled to provide many replicates of time series data of equal length as the original data. The time series data for each replicate is obtained by randomly selecting data value from any year in the original time series continuously until a time series of equal length as the original data is constructed.

Table 1. Mann Kendall test results with bootstrap (S: significant, NS: no significant).

	MEAN	MANN KENDALL TEST	CRITICAL VALUES (STATISTIC TABLE)			CRITICAL VALUES (RESAMPLING)			RESULTS
			a=0.1	a=0.05	a=0.01	a=0.1	a=0.05	a=0.01	
Agouim (1963-2004)	190.5	-2.872	1.645	1.96	2.576	1.626	1.875	2.633	S (0.01)
Ait Mouted (1964-1998)	285.9	-1.818	1.645	1.96	2.576	1.647	1.96	2.556	S(0.1)
Mansour-Eddahbi (1979-2005)	233.6	0.5	1.645	1.96	2.576	1.605	1.897	2.418	NS
Iffre (1964-2004)	206	-0.528	1.645	1.96	2.576	1.617	1.988	2.482	NS

The *Mann Kendall test* results presented in Tab.1 show the presence of significant decreasing trend at the significant level of 1% for Agouim and 10% of Ait Mouted time series, and an absence of trend in Mansour-Eddahbi and Iffre at the significance level of 10%.

DETECTION OF CHANGE IN THE EVAPORATION TIME SERIES

Most of water resources systems were based on the stationnarity of hydrology hypothesis. If this hypothesis of stationnarity is inadmissible, the current systems can be under or overestimated. The presence of trends and change in the hydro-meteorological series can be due to climate change, to the percentage of exploited lands (urbanization, deforestation), to the change of the resources management methods. The change of the temporal series can occur gradually, brutally or under a more complex form. He can affect the mean, the median, the variance or more other data aspects. The detection of change in evaporation data was made through two statistical tests: *Cumulative Deviation test* and *Student's t-test*.

Cumulative deviation

The cumulative deviation method is a parametrical test which examine if the mean in two parts of the same series are different for unknowing change time. The test supposes that the data are normally distributed. The purpose of this test is to detect a change in time series mean after *m* observations:

$$E(x_i) = \mu \qquad i = 1,2,3,\ldots\ldots,m$$

$$E(x_i) = \mu + \Delta \qquad i = m+1, m+2,\ldots\ldots,n$$

Where $\boldsymbol{\mu}$ is the mean before the change and $\boldsymbol{\Delta}$ is the change of mean. The cumulative deviations of means are calculated as follows:

$$S_0^* = 0 \qquad S_K^* = \sum_{i=1}^{K} (x_i - \overline{x}) \qquad K = 1,2,3,\ldots\ldots,n$$

And the adjusted and re-measured partial sums are obtained by dividing the values of $\boldsymbol{S_k^*}$ by the standard deviation:

$$S_K^{**} = S_K^* / D_x$$

$$D_x^2 = \sum_{i=1}^{n} \frac{(x_i - \overline{x})^2}{n}$$

The *Q* statistic test is:

$$Q = \max\left|S_K^{**}\right|$$

The test is calculated for every year; and the change point is indicated by the highest value.

Student's t-test

The Student's t-test is a non parametrical method which analyse if the mean for two different periods are different. The test supposes that the data are normally distributed. The *Student's t-test* is:

$$t = \frac{(\overline{x} - \overline{y})}{S\sqrt{\frac{1}{n} + \frac{1}{m}}}$$

Where $\overline{x}$ and $\overline{y}$ are respectively the mean of the first and the second period, $\boldsymbol{m}$ and $\boldsymbol{n}$ present respectively the number of observations in the first and the second period, $\boldsymbol{S}$ is the empirical standard deviation of $\boldsymbol{m}$ and $\boldsymbol{n}$ observations.

Results

The Student's t-test seems to be the easier and the most reliable statistical tool to test the distances between two data samples of different size.

The *Student's t-test* reveals in Tab. 2 the presence of mean change before and after the years of break:

- Iffre: the mean of 1964–1983 (Mean=*212*) and 1984–2004 (Mean=*200*) does not present any significant difference (a=0.1).
- Mansour-Eddahbi: the mean of 1979-1991 (Mean=*231*) and 1992-2005 (Mean=*235*) does not present any significant difference (a=0.1),
- Agouim: the mean of 1963–1983 (Mean=*212*) and 1984-2004 (Mean=*168.8*) is significantly different at the significance level of (a<0.01); the mean of the first period is bigger than the second.
- Ait Mouted: the mean of 1964-1980 and 1981-1998 does not present a significant difference.

Table 2. Results of cumulative deviation and Student tests *(S: significant, NS: no significant).*

		Tests values	Statistic table			Bootstrap			Results
			a=0.1	a=0.05	a=0.01	a=0.1	a=0.05	a=0.01	
Iffre	Cumulative deviation	1.459	1.131	1.261	1.502	1.113	1.238	1.492	S(0.05)
	student	1.459	1.684	2.021	2.704	1.729	2.045	2.646	NS
Mansour Eddahbi	Cumulative deviation	0.935	1.114	1.234	1.448	1.12	1.226	1.358	NS
	Student	-0.439	1.706	2.056	2.779	1.644	1.904	2.251	NS
Agouim	Cumulative deviation	1.721	1.132	1.262	1.504	1.15	1.268	1.493	S(0.01)
	Student	3.194	1.684	2.02	2.702	1.725	2.037	2.615	S(0.01)
Ait Mouted	Cumulative deviation	1.401	1.125	1.25	1.48	1.136	1.266	1.55	S(0.05)
	Student	0.401	1.692	2.034	2.732	1.598	1.867	2.306	NS

The comparison of the mean in two different periods by cumulative deviation test shows in Tab.2 a significant mean difference in the data series:

- In Iffre the data show a significant change at the significance level of 5%; the mean of 1964-1977 period is bigger than that of 1977–2004
- In Agouim, the data show a significant change at (a<0.01) ; the mean of 1963-1980 period is important than that of 1980–2004
- In Ait Mouted, the mean over the period of 1964–1990 is much important than that of 1990–1998 at the significance level of (a<0.05)
- The Mansour-Eddahbi data series does not present a significant change.

COMPARISON BETWEEN RAINFALL AND EVAPORATION DATA SERIES BEHAVIOUR

Distribution and dispertion of data

In probability theory and statistics, the coefficient of variation (*CV*) is a normalized measure of dispersion of a probability distribution. It is defined as the ratio of the standard deviation σ to the mean μ:

$$c_v = \frac{\sigma}{\mu}$$

The analysis of the variation coefficient shows in Figure 3.a, that the rainfall data are more scattered than those of evaporation. The normal statistical fluctuations give variations producing asymmetries. To distinguish between statistical and actual asymmetries, it is necessary to measure the distribution asymmetry. The most used asymmetry coefficient was the “skewness”. Qualitatively, a negative skew indicates that the tail on the left side of probability density function is longer than the right side and the bulk of the values (including the median) lie to the right of the mean. A positive skew indicates that the tail on the right side is longer than the left side and the bulk of the values lie to the left of the mean. A zero value indicates that the values are relatively evenly distributed on both sides of the mean, typically but not necessarily implying a symmetric distribution. The study of the distribution of the series analyzed by the calculation of “Skewness” shows in Figure3.b a positive asymmetry for the rainfall variable; while the distribution of the evaporation data extend out towards negative values. The two parameters do not show a normal distribution.

The measure of the random rainfall and evaporation variables distribution show a positive asymmetry for the precipitation; while the distribution of evaporation spreads out towards negative values.

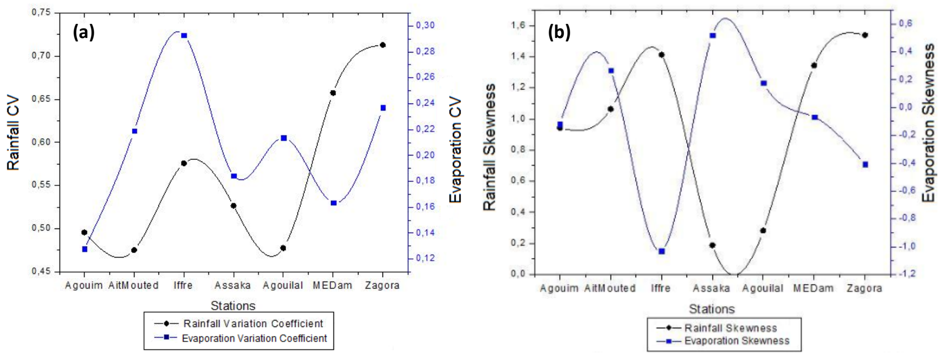

Figure 3. Statistical Comparison of the rainfall and Evaporation parameter. (a) Variation Coefficient. (b) Skewness.

Cross correlation test

The cross correlation is a standard method which aims at estimating the degree of correlation between two variables and the statistical meaning of the obtained results. The cross correlation is sometimes used in statistics to indicate the covariance *Cov (X, Y)* of random vectors *X* and *Y*; to distinguish this concept of the “covariance” of a random vector X, which is understood as being the covariances matrix of *X* coordinates.

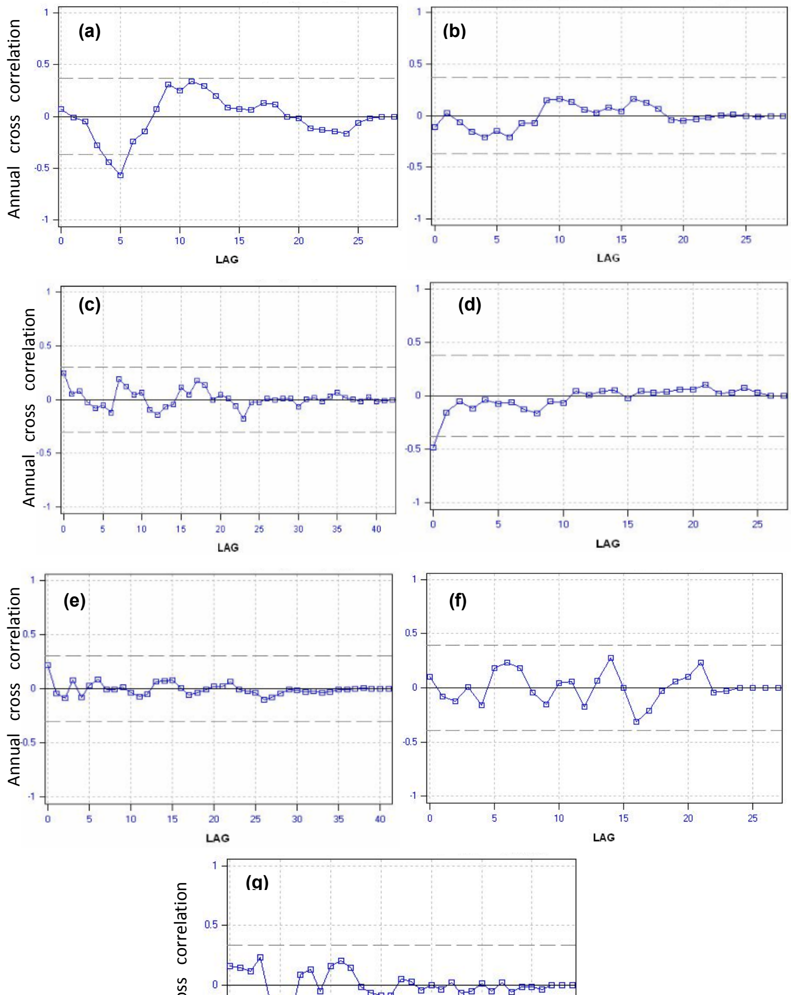

Figure 4. Diagrams representing the Cross-correlation between Mean annual rainfall data and the mean annual evaporation data measured according to Piche evaporometer. (a) Agouilal (b) Agouim (c) Ait Mouted (d) Assaka (e) Iffre (f) Mansour-Eddahbi (g) Zagora.

The mean annual evaporation data used in this analysis are measured according to the Piche evaporometer. The record's length of correlated series is variable according to data stations, the minimal period is 28 years, and the maximal period is 42 years. The results of the cross correlation test applied on seven stations show in Figure 4; a negative values and values close to 0 which can be explain by the fact that the evaporation and rainfall data are independent or conversely proportional.

CONCLUSION

Most water resources projects are designed and operated based on the historical pattern of water availability, quality and demand, assuming constantly climatic behaviour. The investigation of present and probable future climate change pattern and their impact on the water resources, appropriate adaptation strategies may be implemented. Rainfall and evapotranspiration are the most important parameter to diagnose the climate change and variation. In this current study, the statistical tests reveal the existence of change and variabilities in the time series values through decades but do not certainly prove the size of change which can be insignificant; Particularly for Mann Kendall test which do not expect the normal distribution of time series. According to the variation and change analysis tests, the evaporation time series tend to a diminution for the last decade. Indeed the climate of Morocco knew an important phase of aridity and especially that registered in 1980. The cross correlation between rainfall and evaporation has a tendency to be independent towards the upstream stations (values close to 0).

The application of Mann Kendall test on the mean annual evaporation showed homogeneity of the studied series with the presence of a decreasing trend for Agouim and Ait Mouted data series, while the series of Iffre and Mansour-Eddahbi do not present a significant trend. The Student's t-test does not show significant mean change except for Agouim where the evaporation during period of (1963–1983) presents a more important mean than that of the period of (1984–2004). The detection of mean change over two different periods according to the year of break via cumulative deviation test reveals a significant variation of mean which aims to decrease for the last twenty years. The comparison of the mean annual precipitation and evaporation series on various time intervals shows a conversely proportional relation between these two parameters which tend to be autonomous.

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