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Biophysical Effects of Evapotranspiration on Steppe Areas: A Case Study in Naâma Region (Algeria)

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Abstract

The Algerian steppe is of great interest in terms of vegetation, mainly in the Naâma region. This steppe vegetation is generally composed of annual and perennial grasses and other herbaceous plants, as well as, bushes and small trees. It is characterized by an arid Mediterranean climate where the average annual precipitation (100 to 250 mm) is insufficient to ensure the maintenance of the vegetation, in which the potential evaporation always exceeds the precipitations. This aridity has strong hydrological effect and edaphic implications from which it is inseparable. Water losses are great than gains due to the evaporation and transpiration from plants (evapotranspiration). The wind moves soils for one location to another, and causes a strong evapotranspiration of the plants, which is explained by a strong chronic water deficit of climatic origin of these compared to the potential evapotranspiration, opposed to a humid climate. Evapotranspiration is certainly closely linked to climate factors (solar radiation, temperature, wind, etc.), but it also depends on the natural environment of the studied region. Potential evapotranspiration (PET) data estimated from Thornthwaite's method for the three stations (Mécheria, Naâma and Ainsefra). The average annual value of potential evapotranspiration is of the order of 807 mm in Mécheria, of 795 mm in Naâma de and in Ainsefra of 847 mm. It is more than 3 times greater than the value of the rainfall received. This propels it globally in the aridity of the region and from which the water balance of plants is in deficit. The potential evapotranspiration of vegetation in arid areas is very important due to high temperature and sunshine. During the cold season, precipitation covers the needs of the potential evapotranspiration and allows the formation of the useful reserve from which the emergence of vegetation. From the month of April there is an exhaustion of the useful reserve which results of progressive deficit of vegetation. Faced with this phenomenon of evatranspiration, the steppe vegetation of the region then invests in "survival" by reducing the phenomena of evapotranspiration, photosynthetic leaf surfaces, in times of drought. These ecophysiological relationships can largely explain the adaptation of steppe species (low woody and herbaceous plants) to the arid Mediterranean climate. Mechanisms and diverse modalities were allowing them to effectively resist for this phenomenon. The adaptation of the steppe vegetation by the presence of a root system with vertical or horizontal growth or both and seems to depend on the environmental conditions, and by the reduction of the surface of transpiration, and by the fall or the rolling up of the leaves, and by a seasonal

reduction of transpiration surface of the plant to reduce water losses during the dry season (more than 6 months) of the year. Some xerophytes produce “rain roots” below the soil surface, following light precipitation or during dew formation. Other persistent sclerophyllous species by which decreases transpiration by the hardness of the leaves often coated with a thick layer of wax or cutin.

Keywords: evapotranspiration, climate, factors, Naâma, vegetation, Algeria

1. Introduction

The South Oranian steppe of Naâma is characterized by sparse vegetation and only drought tolerant plants that can live there. The steppe vegetation is therefore made up of open grassy formations, revealing bare soil between the plants and the amount of existing plant matter per unit area and roughly proportional to the precipitation received [1]. They are plant formations of a steppe character, primary or secondary, low and open in their typical physiognomy, and mainly subservient to arid and desert areas (rainfall < 350 mm) [2].

Soil, vegetation and atmosphere form a single continuous system in which water circulates at a negative energy gradient, water moves through the soil and then absorbed by roots, and from branches to leaves and then evaporated into intercellular cavities of leaves, and then diffused through the stomata to the layer of calm air in contact with the surface of leaves and finally to the outside atmosphere [3]. In the water cycle, water inputs correspond to precipitation and water losses are due to evapotranspiration, runoff and infiltration. Therefore, part of the precipitation can be intercepted by vegetation and returned to the atmosphere by evapotranspiration (ET) or sublimation [3].

Evapotranspiration is defined as “the response of vegetation to natural climatic conditions in relation to the physiological properties of the plant and its water resources. It is a complex climatic parameter, knowledge of which has significant practical interest at the moment of the estimation of water reserve of soils and of water requirements of crops and vegetation, and in the estimation of the volumes of water necessary for the development of plants. Evapotranspiration is also an indicator of interest in studies concerning climate change [4]. Evapotranspiration can act on the water balance and modify its various components through vegetation. Also, evapotranspiration plays a key role in the evaluation of the climatic capacities of a given region and is considered to be the indicator of optimal vegetation development [5].

This study aims to estimate the evapotranspiration in this region, and evaluate its impact on vegetation, in order to better understand the adaptation of this vegetation on this arid climate. In this chapter, we begin to present the basic concepts relating to the notions of water balance, the phenomenon of evapotranspiration and the methods of its evaluation. Next, we will describe the general characteristics of the steppe environment of the Naâma region (geographic location, climate, natural resources, etc.), then we will present the methodology adopted to achieve the study objectives, as well as, the impact of the evapotranspiration on vegetation. Finally, we end this work with a conclusion and some recommendations.

1.1 Theoretical framework on evapotranspiration

1.1.1 Notions of evapotranspiration

Evapotranspiration can be defined as the loss of water through soil and plant surface, usually expressed in mm/day. Indeed, the term “evapotranspiration” (ET)

designates the water losses of a plant cover depending on the soil water reserve, the stage of vegetation development and the atmospheric environment [6]. Evapotranspiration is a combination of two terms, namely, evaporation (from a surface, from a body of water), and transpiration (from plants). It constitutes a fundamental characteristic of the climate, represents the cumulative evaporation of the soil and the transpiration of plants [7].

Evapotranspiration is a combination of two processes:

- **Evaporation**, is the passage of water from the liquid state to the gaseous state in the form of vapor, or more precisely direct evaporation, refers to the water that evaporates from a soil or from water body to the atmosphere [8].
- **Transpiration**, is the loss of water in the form of vapor by the plant. At the leaf scale, it is caused by the difference in vapor pressure between the intercellular spaces of the leaves and the surrounding air [9, 10]. Transpiration is the driving force behind the transfer of water through the plant: a difference in water potential is created between the leaves and roots, which are at the origin of the absorption flow (a hydraulic suction pump transferring the water from the soil to the atmosphere, i.e. the soil-plant-atmosphere continuum) [11].

1.2 Different types of evapotranspiration

- **Potential evapotranspiration (PET)** is the maximum water consumption of an active vegetation cover, dense and spread over a large area and well supplied with water. It is considered to be the upper limit of evapotranspiration for a crop in a given time [12]. The evapotranspiration of a plant cover is said to be potential when the energy available for vaporization is the only factor limiting this first. It is also called the reference evapotranspiration (ET_0). The evapotranspiration of a low, contained and homogeneous plant cover whose water supply is not limiting and which is not subject to any nutritional, physiological or pathological limitation [13].
- **Real evapotranspiration (RET)** is a key term in the water balance [14]. It is linked to maximum evapotranspiration by a stress coefficient. It designates the amount of water actually lost in the form of water vapor by the plant cover when the water supply is not optimally assured. It corresponds to the effective evapotranspiration of a plant cover when the water supply is not optimally assured. This means that the limiting factor can be of a climatic nature (insufficient rainfall for example), or of a pedological nature (rapid exhaustion of the easily usable water reserve in the soil), or of a physiological nature (for example, plant incapable of ensuring, from the soil to the leaves, a sufficient flow of water to use all the energy that might be available for vaporization [15].
- **Maximum evapotranspiration (MET)** is linked to PET by a crop coefficient (K_c). This is the amount of water lost by vegetation enjoying an optimal water supply (good soil fertility, good sanitary condition, etc.). The maximum evapotranspiration varies during the development of an annual crop, increases gradually with the rate of soil cover by the plant to reach PET and decreases at the end of the vegetative cycle [16]. This form of evapotranspiration (MET) is used by agronomists to determine the water requirements of plants [17–19].

1.3 Climatic factors influencing evapotranspiration

According to Ferchichi (1996) [7], evapotranspiration is certainly closely linked to climatic factors, but it also depends on the natural environment of the region studied, the plant species concerned and soil properties. Evapotranspiration strongly depends on the availability of two factors: abiotic (climatic, geographic: topographic and orographic, hydrological and edaphic: soil) and biotic (biological: vegetation).

Evapotranspiration occurs under the influence of solar radiation, which is the source of energy that allows water to change from liquid to vapor. It depends on two elements: the heat supplied by solar radiation and the quantity of water available in the ground [20]. Evapotranspiration is certainly closely linked to climatic factors (evaporating power): air temperature, temperature of the earth’s surface, wind speed and turbulence, duration of sunstroke or solar radiation, precipitation, relative air humidity and atmospheric pressure.

Indeed, the transpiration process depends on the following parameters: solar radiation, temperature, humidity, wind speed, the water vapor concentration gradient and therefore the water vapor pressure between the spaces substomatics of the leaf and the atmosphere, physiological mechanisms and metabolic activity of the plant, density of the root system, type of plant cover (structure, size, leaf area, presence or absence of leaves, nature of pigmentations, etc.). Finally, the process of evaporation depends on temperature, precipitation, air humidity and plant cover... (Figure 1).

1.4 Methods used for the estimation of evapotranspiration

Evapotranspiration is an important component of the water balance, involving both physical and biological processes. Many methods used for the estimation of evapotranspiration, which have been proposed by different authors. Each method is distinguished by the parameters taken into consideration, by the climatic conditions in which it was developed and by its application limits. Evapotranspiration can be evaluated by several methods (direct and indirect), which take into account

Figure 1.
Different streams of the water balance.

different meteorological parameters (climatic, energetic) in relation to soil and vegetation parameters. In the meteorological stations of Naâma region, the evapo-transpiration is measured directly with the lysimeter and evaporation pan and is estimated indirectly by using methods (equations) such as those of Thornthwaite, (1944), Penman (1948), Turkish (1961), etc.

2. Material and methods

2.1 Presentation of the study area

2.1.1 Geographical location

The wilaya (province) of Naâma is part of the southern high plains of Algeria; it extends between latitude 32° 08'45" and 34° 22'13" North, and longitude from 0° 36'45" to 0° 46'05" west. It covers an area of 3 million hectares. It is occupied by a population located along the Oran-Bechar road axis, i.e. 37% of the total area, which translates poor use of space. The region of Naâma has a large set of ecosystems and biological diversity. Administratively, the province of Naâma is limited (**Figure 2**):

- In the north by the provinces of Tlemcen and Sidi Bel Abbès,
- In the east by the province of El-Bayadh,
- In the south by the province of Béchar,
- In the west by the Algerian-Moroccan border of 275 km long.

Figure 2.
Geographic location of the study region (Naâma, Algeria).

2.1.2 Biophysical characterization

The analysis of the biophysical environment will be done on the basis of the analysis of factors (geographic, hydrographic, pedological, climatic, etc.), in order to allow us to identify and characterize the potentialities and physical constraints as well as their interaction.

2.1.2.1 Geomorphological framework

From a geomorphological point of view, the territory of the Naâma region is formed on immense depressed plain located between the two Atlas (Tellien and Saharan). There are three homogeneous geographic areas (**Figure 2**):

- Steppe space (high steppe plains) shows a vast plain (74% of the territory of the province) whose altitude increases significantly towards the south (1000 to 1300 m). It is characterized by the predominance of pastoral activity.
- Mountainous area is located in the southwest region reaching an altitude of 2000 meters and occupying 12% of the territory of the province. It is a part of the Ksour Mountains and the foothills of the Saharan Atlas. It is characterized by oasis-type agriculture.
- A pre-Saharan area covers an area of around 14% of the total area of the province.

2.1.2.2 Soil framework

According to the work of (Pouget [21]; Djebaili et al. [22], Halitim [23]; Haddouche [24] and Bensaid [25]), the soils of the Naâma region are generally classified as follows:

- Raw mineral soils are represented by raw mineral soils from erosion, raw mineral soils from alluvial input and raw mineral soils from wind input.
- Poorly evolved soils: Present an AC profile, a low degree of evolution and poor alteration in organic matter devoid of clay-humic complex, they are located at the edges of wadis and they surround raw mineral soils, they cover the glaciis of the North South-East plain of the province.
- Calcimagnesium soils (Calcimorphic soils) called rendzines are located on the slopes of mountains. They are the most common type of soil in this area, and occupy vast surface. According to the geomorphological characteristics, the Halomorphic soils are the most dominant, mainly located in the Chott-Chergui, the sebkhas and the Mekmen. These soils support halophyte vegetation based on *Atriplex halimus*, *Atriplex glauca*, *Frankenia thymifolia*, *Salsola sieberi*.

2.1.2.3 Biogeographical framework

The North African steppes in general and the Algerian steppes in particular are part of the Mauretano-steppe floristic domain defined by Maire [26]. This area belongs to the Mediterranean floristic region, therefore to the Holarctic Empire.

Biogeographically, the study region belongs to the Mediterranean area, to the high-lands sector and to the Saharan Atlas sector according to the Quézel and Santa [27].

2.1.2.4 Biological framework

The steppe space in the Naâma region is characterized mainly by plant formations of herbaceous, sub-shrub and shrub types. The steppe vegetation is characterized by the abundance either of cespitose grasses (*Stipa tenacissima*, *Lygeum spartum*, *Stipagrostis pungens*) or of chamaephytes (*Artemisia herba-alba*, *Hammada scoparia*), but also by the frequency of annual species. For the shrub layer is quite common in arid and pre-Saharan areas (*Ephedra alata*, *Retama retam*, *Salsola vermiculata*, *Thymellaea microphyla*).

For the shrub layer is characterized by the presence of forest species (*Quercus ilex*, *Pinus halepensis*, *Juniperus phoenicea*, *Juniperus oxycedrus*, *Pistacia atlantica*) in the mountains such as the case in Djebels (mountains) of Aissa, Merghad, Mekther, etc. **Figure 3** below shows a map of the main plant formations in the study region.

2.1.2.5 Climate framework

The climate is Mediterranean with a bioclimatic gradient decreasing from North to South, ranging from semi-arid to lower arid and pre-Saharan. Rainfall is low and irregular, varying from 190 to 250 mm/year. The frequency of drought seems to be increasing in recent decades.

2.1.3 Methodological approach

2.1.3.1 Bioclimatic study

As part of our study, we took into consideration, as climatic parameters: rainfall and temperature because they represent the essential element of plant growth, soil

Figure 3.
Map of the main plant formations in the Naâma region [28].

formation and evolution. Several studies were carried out about the climate of steppe regions in Algeria [29–36].

The study of the climate and bioclimate is based on the automated processing of old meteorological data [29], taken over 25 years (1913–1938) and from the recent period (1990–2014). All data are collected from the National Meteorological Office (NMO) [37].

- Presentation of weather stations

From a climatic point of view, the Naâma region inscribes its territorial limits on three distinct geographic natural domains:

- Steppe area (High Steppe Plains): it is covered by 2 meteorological stations: Naâma and Mécheria.
- Atlas area (Saharan Atlas): it is covered by a single meteorological station of Aïn Sefra (**Table 1**).

- Presentation of climate data

Temperature and precipitation values are synthesized to determine climatic parameters for the entire study region by extrapolation. Data are listed in **Table 2**.

Rainfall: The geographical location of the study region shows decreasing rainfall gradient from North to South. The distribution of the average monthly rainfall during the periods 1913–1938 and 1990 to 2014 is presented as follows.

Temperatures: Temperatures are an important component of plant life, especially the two extremes: The lowest average temperatures are in January for the three stations, while the highest averages are in July for the three stations (**Table 3**) according to data from NMO (**Table 4**) [37].

Calculation of different climatic parameters

De Martonne aridity index: The aridity index is a quantitative indicator of the degree of water scarcity present in a given location. The De Martonne index is given by the formula below [38].

$$I = R/T + 10 \tag{1}$$

Where: R = Average annual rainfall in mm and T = Annual average temperature in °C. When the index is low, the climate is more arid, and vice versa (**Table 5**).

Calculation of thermal continentality: The thermal continentality is given by the Debrach method [39]. It is distinguish four types of climates:

- Islander climate: $M - m < 15^{\circ}\text{C}$,
- Coastal climate: $15\text{ }^{\circ}\text{C} < M - m < 25^{\circ}\text{C}$,

Station	Latitude	Longitude	Altitude
Mécheria	33° 31' N	00° 17' W	1149 m
Naâma	33° 16' N	00° 18' W	1166 m
Aïn Sefra	32° 45' N	00° 36' W	1058 m

Table 1.
Main reference weather stations in the study region [36].

Station	Rainfall	J	F	M	A	M	J	Jt	A	S	O	N	D	Annual
Mécheria	P1 (1913–1938)	21,00	24,00	32,00	29,00	25,00	14,00	5,00	8,00	34,00	29,00	43,00	29,00	293,00
	P2 (1990–2014)	1849	17,88	27,95	26,24	21,05	10,60	5,28	10,14	26,34	35,52	26,98	16,62	243,11
Naâma	P1 (1913–1938)	—	—	—	—	—	—	—	—	—	—	—	—	—
	P2 (1990–2014)	13,57	15,37	25,47	18,15	18,05	14,18	5,64	14,61	23,51	31,32	26,68	12,14	218,75
Ain sefra	P1 (1913–1938)	10,00	10,00	14,00	9,00	15,00	28,00	8,00	7,00	15,00	29,00	29,00	18,00	192,00
	P2 (1990–2014)	15,65	11,97	25,50	18,67	14,52	8,31	4,72	10,68	21,51	35,79	22,75	9,52	199.64

Table 2.
Distribution of average monthly precipitation [37].

Station	Period	J	F	M	A	M	J	Jt	A	S	O	X	D
Mécheria	P1 (1913–1938)	6,25	7,60	10,70	14,30	17,60	23,20	27,70	27,45	22,60	16,40	10,10	6,65
	P2 (1990–2014)	6,95	8,06	11,31	14,12	22,91	23,87	27,90	27,12	22,03	17,01	11,01	7,54
Naâma	P1 (1913–1938)	—	—	—	—	—	—	—	—	—	—	—	—
	P2 (1990–2014)	6,07	7,49	11,13	14,35	18,97	24,56	28,61	27,79	22,64	17,20	10,66	7,13
Ain sefra	P1 (1913–1938)	6,05	8,35	10,70	15,65	19,40	24,05	28,40	27,20	23,70	17,05	10,60	6,90
	P2 (1990–2014)	7,44	9,12	12,69	15,95	20,60	25,84	29,53	28,53	23,85	18,24	11,90	8,29

Table 3.
Monthly mean temperatures (°C) (from 1913 to 1938 and 1990–2014) [37].

Station	Period	M (°C)	m (°C)	P (mm)
Mécheria	P1 (1913–1938)	35,1	1,5	293,0
	P2 (1990–2014)	36,78	1,49	243,1
Naâma	P1 (1913–1938)	/	/	/
	P2 (1990–2014)	36,8	0,32	218,7
Aïn Sefra	P1 (1913–1938)	37,6	−0,3	192,0
	P2 (1990–2014)	38,34	0,57	199,6

Table 4.
Average values of temperatures and rainfall in the study stations.

Aridity index (I)	Type of climate
$I < 5$	Hyper-arid climate
$5 < I < 7,5$	Desert climate
$7,5 < I < 10$	Steppe climate
$10 < I < 20$	Semi-arid climate
$20 < I < 30$	Mild climate

Table 5.
De Martonne aridity index class [38].

- The semi-continental climate: $25^{\circ}\text{C} < M - m < 35^{\circ}\text{C}$;
- Continental climate: $M - m > 35^{\circ}\text{C}$.

Where: M: average temperatures of the maximums of the hottest month. m: average minimum temperatures of the coldest month.

Seasonal regime: The seasonal regime presents the seasonal variation: the sum of the seasonal rainfall of Winter, Spring, Summer and Autumn. According to Despois [40], the study of the rainfall regime is more instructive than comparing annual averages or totals.

For this purpose, we calculated the amount of rainfall for all the study stations, during the four seasons.

- Autumn (A): September, October, November
- Winter (W): December, January, February.
- Spring (Sp): March, April, May.
- Summer (S): June, July, August.

Climate summary: Climate synthesis is based on the search for formulas that allow the action of several ecological factors to be reduced to a single variable. For this, several climatic indices, taking into account variables such as rainfall and temperatures, have been formulated for a synthetic expression of the regional climate.

We will retain the pluviometric quotient of Emberger [41, 42], which remains the most effective index in the description of the Mediterranean climate, the xero-thermic index of Bagnouls and Gaussen [43] and thermal continentality and rain.

Several methods and indices have been used in the climatic classification of the Mediterranean region, including the method of Bagnouls and Gaussen [43, 44] and that of Emberger [42].

Pluviothermal quotient: Emberger [42] proposed a pluviothermal quotient, which tells us about the xeric character of the vegetation and which takes into account temperatures and rainfall. The latter exercises a preponderant action for the definition of the global drought of the climate. Emberger's quotient is specific to the Mediterranean climate. The quotient Q_2 was calculated by the following formula [42]:

$$Q_2 = [2000R/M^2 - m^2] \quad (2)$$

Where: Q_2 : the pluvio-thermal quotient, R: Average annual rainfall in (mm), M: the average of the thermal maxima of the hottest month in Kelvin, m: the average of the thermal maxima of the coldest month in Kelvin. The Q_2 allowed us to locate our weather stations on the Emberger climagram.

Bagnouls and Gaussen temperature diagram: The ombrothermal diagrams of Bagnouls and Gaussen make it possible to compare the evolution of the values of temperatures and precipitations. On this subject, Emberger specifies: "a climate can be meteorologically Mediterranean, possessing the characteristic Mediterranean pluviometric curve, without being so ecologically or biologically, if the summer drought is not accentuated".

The study region is characterized by minimum temperatures between: - 0.3 and 2.12° C. Le Houérou *et al.* [45] consider that the Algerian steppes are surrounded by isotherms "m" - 2 and 6° C, and that M-m varies little and remains approximately equal to 32.6–37.9° C. These temperatures explain the absence of certain species whose life is linked to temperate winters.

2.1.3.2 Methods for estimating evapotranspiration

As part of this work, evapotranspiration is calculated for the three meteorological stations in the Naâma region using the Thornthwaite method.

The Thornthwaite Method is an empirical formula for estimating potential evapotranspiration, relatively simple to implement, since it requires few data (average air temperatures, in particular). One of the drawbacks of the Thornthwaite method is its monthly time step for calculating potential evapotranspiration.

Calculation of PET is done by applying Thornthwaite's formula; it is a simple expression suitable for arid climate. This Thornthwaite Method is one of the most widely used formulas for the calculation of evapotranspiration is that of Thornthwaite [46].

It has been tested in several regions of Algeria and in the Mediterranean because it gives acceptable results.

By statistically fitting the results of experimental measurements of the PET to climatological data, Thornthwaite established a non-linear relationship between the mean monthly PET and the monthly mean temperature (T_m) expressed like this:

Potential evapotranspiration: it is the consumption of water, under the combined action of the evaporation of water from the soil and the transpiration of the plant. For its estimation, methods based on climatic variables are used. However, the choice depends mainly on the type of climate data available and the type of climate in the region. However, ETP data for the three stations (Mécheria; Naâma, Ain Sefra) are estimated using the Thornthwaite method [46].

$$ETP = 16(10 \times T/I)^a K \tag{3}$$

Where PET: is the monthly potential evapotranspiration, expressed in mm T: the monthly average temperature of the month considered in degrees Celcius.

a: Coefficient given by the expression: $a = 1.6 (I/100)^{+0.5}$.

where the annual thermal index I is equal to the sum of the twelve values of the monthly thermal index: $i = (T/5) 1.514$ K: Correction coefficient, which depends on the latitude i: monthly thermal index I: Annual thermal index.

$$I = \sum_{m=1}^{12} i(m) i(m) = \left[\frac{\overline{T}(m)}{5} \right]^{1.514} \tag{4}$$

Real evapotranspiration (RET) or flow deficit: This is the quality of water that is actually evaporated or transpired by the soil, plants and free surfaces. The RET can be estimated by several methods; for our case we have chosen the Turkish formula [47]:

$$ETR = \frac{P}{\sqrt{0.9 + \left(\frac{P}{L}\right)^2}} \tag{5}$$

Where: P: designates precipitation in mm.

L: designates a constant dependent on the temperature with $L = 300 + 25T + 0.05T^3$ and T: is the annual average temperature in °C.

The water balance by the Thornthwaite method

Its purpose is to quantify the water transfers resulting from precipitation, and to characterize a soil from a dryness or humidity point of view.

According to Thornthwaite, the water quality needed for a soil to be saturated is equivalent to a 100 mm depth of water, (this is the generally accepted useful reserve). Still according to Thornthwaite, one can establish a monthly hydrological balance during the period (1990–2014), which makes it possible to estimate for each month: the real evapotranspiration (RET).

3. Results and discussion

3.1 Climate analysis

3.1.1 Rainfall

The climate of the Naâma region is Mediterranean; is characterized by a rainy winter and dry summer. The average annual rainfall for the period from 1990 to 2014 is 243.11 mm in Mécheria. It is 218.75 mm in Naâma, and 199.64 mm in Ain Sefra. The months of July are the driest (5.28 mm for Mécheria 5.64 mm in Naâma and 4.72 mm for Ain Sefra); October is the wettest month (35.79 mm for Ain Sefra, 31.32 mm Naâma and 35.52 mm for Mécheria). The monthly breakdown shows that July and August are the two driest months (5.28 mm for Mécheria, 4.72 mm for Aïn Sefra). On the other hand, the same findings (5 mm for Mécheria, 7 mm for Aïn Sefra, 2 mm Naâma) were recorded for the recent period. On the other hand, the months of October and November are the wettest in the two old and recent periods (43 mm for Mécheria, from 29 to 35.79 mm for Aïn Sefra). The comparison between the rainfall series (1913–1938 and 1990–2014) highlights the nature of the decrease or increase in significant rainfall which is a phenomenon of almost general climatic

evolution and which has affected all of the study region or national territory both north and south of the country. Analysis of rainfall data (1990–2014) highlights the nature of the significant decrease or increase in rainfall, which is a phenomenon of climate change. Analysis of the data shows a decreasing rainfall gradient from north to south. In the northern part of the high steppe plains (Naâma, Mécheria), the annual rainfall varies between 200 to 300 mm and in the south (Ain Séfra) the average annual rainfall is equal to 200 mm /year. In fact, precipitation is generally concentrated in the autumn season, especially in October in the form of downpours or thunderstorms. The variability of mean precipitation shows that for the 24-year series, 4 wet years recorded values below the annual average and 5 dry years. This latest drought was manifested by rainfall either too low or too irregular during the year. This period of drought has adverse effects on the steppe environment due to its long duration. The author Rognon [47] considers that a dry year has a different effect depending on whether it follows another dry year or a wet year. We know from the start that the rain regime is irregular in these steppe regions [48]. Several authors (Despois, [40] and Seltzer [29]), confirm this in their studies. The series of pluviometric observations is subdivided into two main periods, namely a rainy period from October to April with a maximum rainfall in October of around 25 mm, and a second dry period from June to August who's rainfall represents only 11% of the annual total (0 to 5 mm). On the other hand, the stations which are in the steppe domain present a structure of precipitation quite different from the Saharan domain. Indeed, if we consider the long series of Seltzer (1913–1938), precipitation is mainly concentrated in the winter season. Precipitation of the recent series (1990–2014), is generally concentrated in the autumn season, especially in October in the form of downpours or thunderstorms. The variability of the mean precipitation shows that for the series of 25 years, 8 years are considered as wet for the first period (1913–1938) and 4 years for the recent series (1990–2014), and 17 years are considered as years dry for the first period and 5 for the second period. In general, the rainfall remains low, irregular with strong inter-annual variations, it is heterogeneous in time and space, this irregularity of frequencies confirms the appearance of dry periods which raged in the region during the years 1992, 1995, 1998, 1999, 2001, 2002, 2004 and 2013. All the indicators converge towards a persistent drought, even if significant rainfall episodes occur they do not manage to fill the deficit to reverse the trend.

3.1.2 Seasonal regime

In general, precipitation is unevenly distributed during the seasons, as shown in **Table 6**. The most important precipitations are those which fall in autumn and spring, compared to that of winter, although that the latter constitute a significant contribution (**Table 6**). The table below shows the calculated seasonal regime of stations in the study region for the two periods.

Period		P1 (1913–1938)					P2 (1990–2014)				
stations	Sp	S	A	W	Regime	Sp	S	A	W	regime	
Mécheria	81,6	27,2	84	85.3	WSpAS	75,25	26,02	88,84	52,97	ASpWS	
Naâma	—	—	—	—	/	61,68	34,45	81,52	41,09	ASpWS	
Aïn Sefra	38	43	73	38	ASWSp	58,69	23,72	80,06	37,16	ASpWS	

**Autumn (A); Winter (W); Spring (Sp) and Summer (S).*

Table 6.
Seasonal rainfall patterns of the old period.

The analysis of the climatic variability of rainfall totals is due to the spatio-temporal seasonal and annual variability of rainfall; this indicates a change in the climate of the study region (**Table 6**). In general, the rainfall is slightly different, where the autumn maximum is constant; some variations show transformations in the seasonal distribution of rainfall. Dominant autumn rains prevail over most of the study area, but the seasonal pattern may be locally modified slightly. The most remarkable fact is that the raising of altitudes characteristically resuscitates the arid climate. The dominant autumn rains prevail over most of the study region, but the seasonal pattern may locally undergo slight modifications between the 2 periods. This variation in seasonal regimes is explained by its essentially orographic character. The most remarkable fact is that the raising of altitudes characteristically resuscitates the arid climate. From south to north/east the formula becomes: AHAE / AHPE /HPAE/AEHP for the old period (1913–1938).

On the other hand, in the recent period (1990–2014), the most remarkable is the consistency of the APHE-type regime for the majority of the study stations. This transition to the dominant autumn rains is indicative of an accentuation of the oceanic character of the climate. This indicates that the rainfall has therefore increased during the cold season, and summer tends to become the dry period. Consequently, the current seasonal regimes (P2) are markedly changed this is explained by their “degree of continentality”.

The distribution of precipitation appears in the study region as an essentially orographic phenomenon: the isohyets reflect the relief. The Tellian and Saharan Atlas plays a much clearer role as a barrier between maritime and continental influences. A succinct explanation of the rains is needed to understand the seasonal variations. In this area the rainy season lasts from 4 to 6 months with some rare local variations, the orientation of the winds appears essential.

Thus, over the past 25 years, the entire study region has been subject to the autumn or winter maximum. The autumn rainy season is prolonged there until December and even January. Here the influence of the relief regenerating the oceanic rain regime is evident. The rainfall figure rises with greater intensity during the winter season: it is therefore a question of relief precipitation. Overall, the evolution of annual precipitation and rainy seasons shows a very moderate decreasing trend between the 2 periods and the following ones, in agreement with observations made at the regional scale. These changes have had repercussions on the vegetation that occurs during the seasonal course of precipitation. The low rainfall is a characteristic of the Saharan climate. However, this region is poorly watered; rainfall is scarce and irregular, often brief (showers), but of high intensity, causing violent floods. The study of seasonal variability is essential, to see if the decrease or increase in rainfall is specific to a particular season or to several seasons, it allows to better visualize the chronology of the seasonal rainfall totals over time. The analysis of monthly average rainfall data makes it possible to better visualize the distribution of the quantities of water recorded at each station and for each month of the year.

3.1.3 Temperatures

Temperatures are an important element for plant life, especially the two extremes: the average of the coldest month's lows and the hottest month's average lows.

Temperatures represent an important element for plant life, especially the two extremes: the average of the minimums of the coldest month and the average of the maximums of the hottest month. We notice a significant increase in maximum temperatures between the two periods; therefore the series of maxima experiences a clear increase which affects all the months of the year, this situation is reflected at

the monthly level where the rise in temperatures fluctuates between 0.3°C to 1.5°C inducing to the annual scale an average increase of 0.5° C. This indicates a more marked global warming of the study region. This change in temperature is manifested by consequences on the metabolism and development of fauna and flora, growth, respiration, the composition of plant tissues and the mechanisms of photosynthesis (**Table 7**).

The highest temperatures are generally recorded in July for the three reference stations. The analysis of the maxima highlights the notion of climatic aridity which tends to strengthen from north to south of the region (**Table 7**). The period of high temperatures, lasting from June to October, can cause scalding due to increased sweating. Therefore, the hottest month of the year for the two thermal series (1913–1938 and 1990–2014) is that of July and August with an average temperature of 29.9° C. (Mécheria) at 36.48° C (Naâma). The analysis of the maxima emerges the notion of climatic aridity which tends to strengthen from north to south of the region, so the average thermal amplitude between the southern and northern zones of the region reaches approximately 0.84° C. This value relative to the spatial extent (in the North–South direction) of the region is relatively high. For the period of low temperatures, from November to February, are at the origin of the intensity of winter frosts which can result in vegetative damage such as necrosis. So the coldest and most severe month is that of January for all the stations during the two thermal study series. On the other hand, the minimum series is experiencing a sharp increase affecting all months of the year with the exception of August. This situation is reflected at the monthly level where the rise in temperatures fluctuates between 0.3° C to 1.5° C inducing on an annual scale an average increase of 0.5° C.

3.1.4 Wind

In the arid region, winds have played and still play a major role in the degradation of vegetation and soil destruction and the building of constrained dune systems; they constitute a permanent threat to biodiversity and infrastructure. Therefore, the wind can reach considerable speeds allowing it to exert erosive actions on the ground by the drying out of the superficial parts of the ground.

3.2 Calculation of the different climatic parameters

3.2.1 Bioclimatic indices

3.2.1.1 De Martonne’s aridity index

The **Table 8** below shows the average annual temperature, the average annual precipitation and the aridity index calculated for the stations during the two periods.

Stations	m °C		Thermal g ³ P	M °C		Thermal g ³ P
	P1 (1913–1938)	P2 (1990–2014)		P1 (1913–1938)	P2 (1990–2014)	
Mécheria	1,5	1,49	−0,01	35,1	36,78	0,74
Naâma	—	0,32	0,32	—	36,8	36,8
AïnSefra	−0,3	0,57	0,87	37,6	38,34	1,68

Table 7.
Thermal differences between P1 (1913–1938) and P2 (1990–2014).

Stations	Period	R (mm)	T° average	De Martone index	Type of climate
Mecheria	1913–1938	278,1	15.9	10,7	Semi-arid
	1990–2014	243,10	16,65	9,12	Steppic
Naâma	1913–1938	/	/	/	/
	1990–2014	218,75	16,38	8,29	Steppic
AïnSefra	1913–1938	192	15.50	7,53	Desert
	1990–2014	199,63	17,66	7,22	Desert

Table 8.
De Martonne’s aridity index.

The comparative analysis of the De-Martone aridity index between the two periods allows us to advance that the study region is strongly marked by increasing aridity which is accentuated from North to South. This is due to the drought induced by the decrease in rainfall and the increase in minimum and maximum temperatures (case of 2001 when the recorded rainfall was 60 mm in Aïn Sefra ...). The values of the aridity index obtained are respectively 8 and 11 depending on the geographical position of the study stations. In the steppe space, for the stations of Mécheria and Naâma are characterized by a semi-arid to steppe climate. In the stations which are in the central part of the region, the Saharan Atlas (Aïn Sefra) the index is 7.53 and reflects a desert-like climate.

3.2.1.2 Thermal continentality

A comparative analysis of the two series (1913–1938) and (1990–2014) recorded at station level (**Table 9**), shows us that the region experiences a contrasting thermal regime, of a continental type. Indeed, the annual thermal amplitude of average temperatures is 30° C to 40° C depending on the North–South orographic gradient. The average seasonal difference can reach more than 30°C, thus promoting soil degradation by the relaxation of friable rocks in terms of erosion in the forms of wind and water erosion.

3.2.2 Climate synthesis

3.2.2.1 The pluviothermal quotient

The mean annual temperatures, the mean annual precipitation, and the calculated rainfall quotients (Q_2) are presented in the following **Table 10**.

Stations	Period	M (°C)	m (°C)	M – m (°C)	Thermal continentality
Mecheria	1913–1938	35,1	1,5	33,6	Semi-continental climate
	1990–2014	36,78	1,49	35,29	Semi-continental climate
Naâma	1913–1938	—	—	—	—
	1990–2014	36,8	0,32	36,48	Continental climate
AïnSefra	1913–1938	37,6	–0,3	37,9	Continental climate
	1990–2014	38,34	0,57	37,77	Continental climate

Table 9.
The thermal continentality of the study stations.

Stations	Period	R(mm)	M(°C)	m (°C)	Q ₂	Bioclimatic stage
Mécheria	1913–1938	278,1	35,1	1,5	28,4	Arid Greater Than Cool Winter
	1990–2014	243,10	36,78	1,49	23,6	Arid Greater Than Cool Winter
Naâma	1913–1938	—	—	—	—	—
	1990–2014	218,75	36,8	0,32	20,6	Medium arid to Cool winter
Aïn Sefra	1913–1938	192	37,6	−0,3	17,4	Saharan Superior to Cold Winter
	1990–2014	199,63	38,34	0,57	18,1	Upper Saharan in Cool Winter

Table 10.
Values of the rainfall quotient.

Figure 4.
Variation of the Emberger climagram, of study stations.

The quotients are inversely proportional to the aridity; this Emberger climagram allows us to determine the bioclimatic stages and the thermal variants (**Figure 4**).

The comparative reading of the pluviothermal climagram (**Table 10** and **Figure 4**) shows a slight change in pluviothermal quotients between the old period and the new period. This type of climate change probably also causes a change in plant formation. For example, the Aïn Sefra station moves from the arid lower level with cold winter in the old period to the upper Saharan level with cool winter in recent times. The Mécheria station is moved from the middle arid stage with cool winter in the old period to the lower arid stage with cool winter in recent times.

3.2.2.2 Ombrothermal diagram of Bagnouls and Gaussen

The analysis of the various ombrothermal curves (**Figure 5**) of the stations compared between the two periods (1913–1938) and (1990–2014), allows us to observe a period of drought varies from 5 to 7 months or more (from the month from June to September) in the resorts of the northern part of the region (steppe plains: Mécheria and Naâma). On the other hand, in the central part of the region (Saharan Atlas: Aïn Sefra), it has a fairly prolonged period of drought that varies

Figure 5. Ombrothermal diagrams of the study stations.

from 10 to 11 months (from March until the end of November). Thus, a fairly short wet period; varies from 4 to 6 months for stations in the steppe space, from one month for stations in the Atlas mountainous space and zero for stations in the Saharan domain.

3.3 Calculation of the hydrological balance and evapotranspiration, real evapotranspiration (RET) and flow deficit

The results obtained from the calculation of evapotranspiration (PET, RET, EUR, Deficit) for the 3 stations are reported in **Table 11**.

3.3.1 For the Mécheria station

We notice that the PET greatly exceeds the precipitation (**Table 11**); and we observe the existence of two very distinct seasons. A surplus season during which rainfall is greater than or equal to the PET (December–February) and the deficit season from March to November. During the cold season, precipitation covers the needs of potential evapotranspiration and allows the formation of Easily Usable Reserve (EUR). From the month of March we have an exhaustion of the EUR which results in an agricultural deficit.

3.3.2 For the Naâma station

We note that from November the precipitation is greater than the evapotranspiration ($R > PET$) (**Table 12**). The Easily Usable Reserve (EUR) reaches its maximum in January, February and March. From the month of March, we record an agricultural deficit of 4.72 mm and which reaches its maximum in July with 181.05 mm. The annual deficit is estimated at 677.89 mm, and the actual evapotranspiration (RET) is equal to 207.93 mm or 95.05% of precipitation.

3.3.3 For the Ain Sefra station

We see that precipitation is less than evapotranspiration throughout the year ($R > PET$) except in January when 15.65 mm of precipitation is recorded (**Table 12**, **Figure 6**). The Easily Usable Reserve (EUR) is zero throughout the year. We record an agricultural deficit throughout the year with a minimum of 3.07 mm in February and a maximum of 190.3 mm in July. The annual deficit is of the order of 746.43 mm. The actual evapotranspiration (RET) is equal to 194.53 or 97% of precipitation.

Station of Mécheria (latitude 33°N, I = 80,03, $a = 1,78$)													
Months	J	F	M	A	M	J	Jt	A	S	O	N	D	Total
T(°C)	6,95	8,06	11,31	14,12	22,91	23,87	27,9	27,12	22,03	17,01	11,01	7,54	16,65
R (mm)	18,49	17,88	27,95	26,24	21,05	10,6	5,28	10,14	26,34	35,52	26,98	16,62	243,1
I	1,64	2,06	3,44	4,81	10,01	10,66	13,5	12,93	9,44	6,38	3,3	1,86	80,03
K	0,88	0,86	1,03	1,09	1,19	1,2	1,22	1,15	1,03	0,97	0,88	0,86	
PET	12,44	16,2	29,61	43,95	104,03	111,91	147,74	140,47	97,02	61,23	28,23	14,38	807,21
ETPc (mm)	13,32	17,06	30,64	45,04	105,22	113,11	148,96	141,62	98,05	62,2	29,11	15,24	819,58
R-PETc (mm)	5,17	0,82	-2,69	-18,8	-84,17	-102,5	-143,7	-131,5	-71,71	-26,68	-2,13	1,38	-576,75
RET (mm)	13,32	17,06	27,95	26,24	21,05	10,6	5,28	10,14	26,34	35,52	26,98	15,24	235,72
EUR (mm)	5,17	0,82	0	0	0	0	0	0	0	0	0	1,38	7,37
Deficit (mm)	0	0	2,69	18,8	84,17	102,51	143,68	131,48	71,71	26,68	2,13	0	583,85
Station of Naâma (Latitude 33°N, I = 78,73, $a = 1,75$)													
Months	J	F	M	A	m	J	Jt	A	S	O	N	D	Total
T(°C)	6,07	7,49	11,13	14,35	18,97	24,56	28,61	27,79	22,64	17,2	10,66	7,13	16,33
R (mm)	13,57	15,37	25,47	18,15	18,05	14,18	5,64	14,61	23,51	31,32	26,68	12,14	218,75
I	1,34	1,84	3,35	4,93	7,52	11,13	14,02	13,42	9,84	6,49	3,14	1,71	78,73
K	0,88	0,86	1,03	1,09	1,19	1,2	1,22	1,15	1,03	0,97	0,88	0,86	
PET	10,14	14,66	29,32	45,74	74,55	117,15	153,03	145,43	101,6	62,81	27,19	13,45	795,07
ETPc (mm)	8,92	12,6	30,19	49,85	88,71	140,58	186,69	167,24	104,64	60,92	23,92	11,56	885,82
R-PETc (mm)	4,65	2,77	-4,72	-31,7	-70,66	-126,4	-181,1	-152,6	-81,13	-29,6	2,76	0,58	-667,13
RET (mm)	8,92	12,6	25,47	18,15	18,05	14,18	5,64	14,61	23,51	31,32	23,92	11,56	207,93
EUR (mm)	4,65	2,77	0	0	0	0	0	0	0	0	2,76	0,58	10,76

Station of Naâma (Latitude 33°N, I = 78,73, a = 1,75)													
Deficit (mm)	0	0	4,72	31,7	70,66	126,4	181,05	152,63	81,13	29,6	0	0	677,89
Station of Ain Sefra (Latitude 32°N, I = 86,99, a = 1,89)													
Months	J	F	M	A	M	J	Jt	A	S	O	N	D	Total
T (°C)	7,44	9,12	12,69	15,95	20,6	25,84	29,53	28,53	23,85	18,24	11,9	8,29	17,66
R (mm)	15,65	11,57	25,5	18,67	14,52	8,31	4,72	10,68	21,51	35,79	22,75	9,52	199,6
I	1,82	2,48	4,09	5,79	8,53	12,02	14,71	13,96	10,64	7,09	3,71	2,15	86,99
K	0,89	0,86	1,03	1,08	1,19	1,19	1,21	1,15	1,03	0,98	0,88	0,87	
PET	11,9	17,49	32,66	50,32	81,6	125,24	161,18	151,02	107,64	64,84	28,92	14,6	847,41
ETPc (mm)	10,59	15,04	33,63	54,34	97,1	149,03	195,02	173,67	110,86	63,54	25,44	12,7	940,96
R-PETc (mm)	5,06	-3,07	-8,13	-35,67	-82,58	-140,7	-190,3	-163	-89,35	-27,75	-2,69	-3,18	-741,37
RET (mm)	10,59	11,97	25,5	18,67	14,52	8,31	4,72	10,68	21,51	35,79	22,75	9,52	194,53
EUR (mm)	5,06	0	0	0	0	0	0	0	0	0	0	0	5,06
Deficit (mm)	0	3,07	8,13	35,67	82,58	140,72	190,3	162,99	89,35	27,75	2,69	3,18	746,43
T: Temperatures(°C); R: Rainfall (mm); PET: Potential evapotranspiration (mm); RET: Real evapotranspiration (mm); EUR: Easily Usable Reserve (mm).													

Table 11.
Calculation of PET by the Thornthwaite method for the study stations (1990–2014).

Station	R (mm)	T (°C)	L	RET (mm)	Conclusion
Mécheria	243,108	16,65	947,03	248,06	RET > R (Rainfall) but noticeably close
Naâma	218,75	16,38	929,24	225,51	
Aïn Sefra	199,63	17,66	1016,88	207,94	

Table 12.
Results of real evapotranspiration (RET) according to the Turkish method.

Figure 6.
Graphical representation of the water balance, mean monthly evapotranspiration according to Thornthwaite.

Examination of the graphs (**Figure 6**) shows that on an annual scale, PET greatly exceeds precipitation and on a monthly scale, there are two very distinct seasons. a surplus season during which precipitation is greater than or equal to the ET from November to March and a deficit season from April to October. Potential (PET) and actual (RET) evaporation vary considerably between ecosystems and sometimes according to seasons. During the cold season, the precipitation covers the needs of the potential evapotranspiration and allows the formation of the RFU from where the vegetation appears. The two curves follow the same trend (**Figure 6**). The period from May to September correlates with the deficit period shown in the ombrothermal diagrams. The actual evapotranspiration (REE) is very low, as the lack of water available for the soil and plants due to drought is a limiting factor.

3.4 Effect of climatic factors on evapotranspiration

According to Emberger [42], the climate in the Mediterranean region is based on “the climatic characteristics which most strongly influence plant life”. In the steppe region where water is a limiting factor, evaporation is very high and reaches its maximum in summer. The slice of water evaporated annually is almost always greater than the total amount of rain that has fallen [29].

In the study area, we found that the PET is significantly higher than the rainfall received. Thus, we consider that this period is a sequence of water deficit (drought) for spontaneous vegetation. To this end, the dominance of PET generates and/or promotes the process of soil degradation and more particularly the silting up of croplands and steppe rangelands [25].

3.4.1 Effect of aridity

The Naâma region corresponds to an arid area, more or less nuanced according to the orography, and the level of the relief and the capacity of the substrates to retain water from precipitation are low. According to Mjeira [17], in any region

marked by aridity, the potential evapotranspiration loss represents 60–80% of the rainfall input.

3.4.2 Temperature effect

Temperature variation between stations shows a period of high temperatures, spanning from June to October, which can cause scalding due to increased transpiration. Periods of low temperatures, from November to February, are the cause of the intensity of winter frosts which can result in vegetative damage such as necrosis. This indicates by Floret & Pontanier [49, 50], the highly contrasted thermal regime is affected by a strong potential evapotranspiration.

3.4.3 Wind effect

Winds are very frequent and violent in the study area, which significantly contributed to the increase in evapotranspiration. According to Escadafal [51], the often strong winds further exacerbate evaporative demand. Khader [52] indicates that wind is a very drying climatic parameter that influences PET by increasing the temperature and simultaneously lowering the humidity of the air which causes it. It accelerates the desiccation of plants, and the increase of evapotranspiration. In the case of the hot and dry southerly “Sirocco” wind blows especially in summer, on average 200 times a year, and lasts more than 45 days a year, accentuating the dry season and bringing back appreciable quantities of sand. This wind causes the soil to dry out by causing a strong evapotranspiration of the plants [53].

3.4.4 Effect of rainfall

According to Derouiche [54, 55], the decrease in rainfall and the increase in temperature represent unfavorable factors for both the soil and the plant. Precipitation cannot compensate for the intense evapotranspiration to which vegetation is subjected during the summer season. The deficit is only made up by the soil’s water reserves according to its capacity to store the precipitation it receives.

3.5 Effect of evapotranspiration on plants of steppe

In the arid region of Naâma, the steppe plants are characterized by a low quotient of potential Precipitation/Evapotranspiration. Thus, the potential evapotranspiration is very high due to heat and sunshine, so rain is especially needed when evapotranspiration is high and precipitation is not sufficient for the normal development of the plant.

The decrease of evapotranspiration leads to the change of the surface energy balance, to an increase of temperatures and to a decrease of the soils capacity to store water for vegetation. Evapotranspiration cools the air through the evaporation of water present in the soil and plants as well as transpiration in the leaves. The climatic aridity has a considerable influence on the growth of steppe plants, because vegetation modifies the water balance of the substrate where it grows, by taking water that is lost through transpiration [25].

Maximum temperatures accentuate water stress; in fact excessive heat causes dehydration resulting from accelerated perspiration. If the soil cannot provide sufficient water supply, there is a loss of turgor. In vegetation, potential transpiration increases with temperature and climatic drought. Therefore, vegetation can act as a brake on the diffusion of water vapor [55]. It helps reduce soil evaporation, reducing net radiation and reducing surface temperature [56]. Vegetation can also

decrease the amount of solar radiation reaching the soil and the temperature of the soil, which can significantly reduce evaporation compared to bare soil [57].

Stomatal regulation is influenced, degree of opening of the stomata depending on climatic factors of evapotranspiration. As soon as a water deficit occurs, the plant adjusts, quickly and reversibly by the process of transpiration, that is to say the water inputs, are carried out at a rate lower than the thermal needs of the plant, the flows of water which cross it by the closing of its stomata (small openings of the leaves, which regulate the gas exchanges between plant and atmosphere).

3.6 Effect of steppe vegetation on evapotranspiration

Plants then invest in “survival” by reducing the phenomena of evapotranspiration, photosynthetic leaf surfaces, in times of drought. It takes place at the level of the stomata of the leaves by reducing their exchange surfaces and closing their stomata. It turns out that vegetation can have an effect on different components of the water balance. As soon as the water conditions at the root level evolve towards drought, the leaves react by closing their stomata, at the same time reducing evaporation, which has the effect of increasing their surface temperature [55, 58]. Because water stress at the roots has a repercussions on the evapotranspiration regime of the leaves.

According to Le Houérou and Popov [59], the reduction in the maximum daily temperature (2.5°C) by woody vegetation corresponds to a decrease of about 147 mm/year of PET at ground level.

The woody tree cover (*Retama retam*, *Pistacia atlantica*) directly reduces solar radiation, air temperature and wind speed on the ground, which can reduced the potential evapotranspiration (PET). Indeed, the natures of the vegetation, woody species consume more water by evapotranspiration than herbaceous species.

Vegetation can increase evapotranspiration through transpiration. This can increase water loss through evapotranspiration. This explains by Carminati *et al.* [60], vegetation can influence evapotranspiration in several ways: vegetation can act on the energy state of soil water through transpiration, which has a linear relationship with the suction exerted by the xylem in dry soils.

According to Yagoub (2016) [54], vegetation regulates surface temperature by absorbing radiant energy and re-emitting it as latent heat via the process of evapotranspiration. Among the regulatory mechanisms, plants are reacted by the reduction of aerial organs to reduce the evaporating surface and the taking of reduced forms (reduction of the leaf system, thorns, hairs, etc.) and the distribution and arrangement of the leaves of a plant structure can act on climatic parameters linked to evapotranspiration (wind speed, solar radiation). In fact, in the underground part, the root system can play a more important role than that of the hydrogeological properties in the useful water reserve.

3.7 Mechanism of adaptation and acclimatization of steppe vegetation

Due to the intensity of evaporative transpiration, the steppe vegetation adapts to withstand the harsh climatic conditions. The difficult climatic conditions, in this steppe area, allow the vegetation to develop an adaptation system for its maintenance and survival. These ecophysiological relationships can largely explain the adaptation of steppe species to the arid Mediterranean climate. Despite the very harsh and very restrictive environmental conditions, there are still geomorphological zones offering more or less favorable conditions for the survival and proliferation of a characteristic spontaneous flora adapted to climatic hazards. These adaptations have shown that steppe vegetation adapted to ecological stress uses one

or more mechanisms to compensate for the inadequate water balance and mitigate the effect of water deficit. They cover the physiological and morphological regulations that allow plants to adapt to a deficient water supply occurring at different scales [61].

3.7.1 Biological adaptation

Biological types are considered as an expression of a flora adaptation strategy to environmental conditions [62], which represent a privileged tool for the description of the physiognomy of vegetation. Emberger [63] affirms that the rate of therophytes increases with the aridity of the environment. Therophytisation is a characteristic of arid areas; it expresses a strategy of adaptation under unfavorable conditions and a form of resistance to climatic rigors [64–66]. Therophytes are more resistant to summer drought than hemicryptophytes and geophytes, since they pass summer as seeds while the others remain as vegetative organs.

According to Raunkiaer [65]; Floret *et al.* [67], chamaephytes are the best adapted for low temperatures and aridity and the absence of these species testifies the anthropization of the environment [68–70].

They partially reduce their organs of perspiration and assimilation in the summer, and can develop some forms of adaptation to drought (reduction of the leaf area) as well as by the development of the root system with the proliferation of thorny species such as *Astragalus armatus*, *Atractylis serratuloides* characteristic of steppe areas [35].

In hemicryptophytes, the perennial organs located at soil level are protected by leaf sheaths (sometimes reduced to fibrils) or old withered leaves as in *Plantago ovata*, *Echium trygorrhizum*. The roots, sometimes considerably developed, are often sheathed with a thick tomentum which fixes the grains of sand and thus protects them from desiccation (*Malva aegyptiaca*, *Paronychia arabica*) [35].

The majority of species of this type are nanophanerophytes or shrub-like pseudo-steppes 1 to 4 m long, including *Nerium oleander*, *Genista saharae*, *Retama raetam*, *Retama sphaerocarpa*, *Rhus tripartita*, *Tamarix articulata*, *Ziziphus lotus*. These types of steppes generally occupy sites with a relatively favorable water balance: terraces of the hydrographic network, dayas, cliffs, deep sandy substrates in topographic position. They often constitute relatively favorable environments [35].

3.7.2 Morphological adaptation

For steppe plant formation, evapotranspiration depends on the leaf area and the stage of development of the plants. The perennial steppe vegetation is therefore adapted to morphological modification during the plant's development stage: Among these forms of adaptation we can cite the decrease in leaf area (plants can have small very thick leaves or reduced to thorns, which allows them to limit their water losses (*Fagonia glutinosa*, *Fagonia latifolia*, *Zilla spinosa*, *Launaea arborescens*). One of the strategies is leaf modification (leaf drop, or leaf area reduction), by microphyllia, most steppe species have very small leaves *Salsola vermiculata* or small *Rhanterium suaveolens* [71].

The flattening of vegetative system is fixed on the ground (*Neurada procumbens*).

Cushion formation (pincushion habit) is also a form of adaptation to the xeric environment with a morphological modification, for example the species (*Anabasis aretioides*, *Teucrium polium*, *Astragalus armatus*, *Atractylus humilis*), can take a ball appearance or pincushion and prickly padded xerophyte includes the species *Oxyhedron* (*Juniperus oxycedrus*). Some plants may have considerably developed underground organs (Rhizomatous) (*Scorzonera undulata*). The leaves can also take

shape in needles or scales; it is the case of the following species *Hammada scoparia*, *Hammada schmittiana*, *Thymelaea microphylla*, *Ephedra alata*, *Genista saharae*, *Retama retam* [35].

According to Ozenda [72], for the case of amaranthaceae (*Zygophyllum album*, *Gymnocarpus decander*), are thus carriers of tiny leaves or even are completely leafless, sometimes the leaves are transformed into thorns to constitute reserves in accumulating water in the tissues (crassulescent leaves or at least semi-succulence and aquiferous tissues). The constitution of water reserves in the tissues and color change where the whitish appearance is the most representative: *Thymelia microphylla*, *Phoenix dactylifera*, ...

A form of sclerophyllia (extravaginate innovations at upper nodes) remarkable in some of the species of Poaceae (*Panicum turgidum*); these innovations protect against wilting [73]. Some trees adapt to the cold by loss of leaves (*Pistacia atlantica*, *Ziziphus lotus*), others will opt for leaves in needles (*Juniperus oxycedrus*, *Juniperus phoenicea*, *Rosmarinus officinalis*) [35].

Thus, the reduction of the vegetative apparatus constitutes a remarkable adaptation to very difficult environmental conditions. This results in the tolerance of certain ligneous plants which opt for a morphological plasticity which reflects the capacity for resilience in response to disturbances of biotic or abiotic origin. These species bury their woody structures below ground level or spread their root system on supports with greater water availability (*Pistacia atlantica*, *Ceratonia siliqua*, *Hammada scoparia*, etc.) [35].

3.7.3 Physiological adaptation

According to Scheromm [74], long water deficits result in progressive changes in the structure of the plant, which aim to reduce its transpiring surface (leaf surface, thickening of the cuticles), but which also induce a decrease in its production. Long water deficits induce more irreversible changes, especially in morphology (reduction of evaporation surfaces).

Thickening of leaf cuticles was reduce the rate of evaporation. The leaf surface is covered with a cuticle formed from cutin embedded in a cuticular wax matrix. It therefore reduces the evaporation of water from the surface of the epidermis. Sometimes the plant spends the dry season as a fleshy bulb or rhizome or as a seed (Therophytes) [75].

The increase in the root system increases biomass and consequently transpiration and reduces evaporation from the soil [76]. The significant growth of the root system compared to the aerial system is drawn from the moisture from the depths [77].

The significant development of the root system, was both on the surface and deeper through taproots (*Hammada scoparia*). This modification is manifested by a horizontal extension of the root system (psammophytes) with a horizontal network of roots and especially of rootlets almost in contact with the soil surface to benefit from the slightest rain or dew. For example, the species *Stipagrostis pungens*, however, has strong vertical roots for anchoring and draws from certain moisture from the depths. Or by a vertical extension of the root system is constituted by a taproot in a fairly large number of perennial species (*Moricandia arvensis*, *Scorzonera undulata*, *Astragalus armatus* ...). Some perennial species may have roots capable of exploring horizons with several meters deep and most often up to the water table. As it progresses in depth to reach the moisture, the root system will present a particularly dense network of rootlets that colonize the inter-leaf spaces of the soil, this is the case of: *Helianthemum hirtum*, *Hammada scoparia*, *Hammada schmittiana*, *Anabasis articulate* and *Astragalus armatus* (Figure 7) [78, 79].

Figure 7.
Some steppe species from the Naâma region (western Algeria).

4. Conclusion

The study region receives an average annual rainfall of less than 300 mm, which explains it's belonging to the arid bioclimatic stage of climate. Precipitation has experienced a very marked interannual irregularity in recent years. The thermal amplitudes were lead to a much faster dieback of annual plants, subjected to intense evapotranspiration.

Climatic data from stations in the study region allowed us to observe the spatio-temporal evolution on a North–South gradient that depends on the irreversible phenomena such as aridity, evaporation (drying out of soils).

This work analyzes the variability of evapotranspiration for steppe vegetation. It is based on climate data measured at three meteorological stations in Naama region. The calculation of evapotranspiration by the water balance method, gave rather satisfactory results insofar as these results oscillate around the normal values of evapotranspiration for the three stations in the study region. Potential evapotranspiration (ETP) data estimated from Thornthwaite's method for the three stations (Mécheria, Naâma and Ain Sefra). The annual average value of potential evapotranspiration is of the order of 807 mm in Mécheria, 795 mm in Naâma de and Ain sefra at 847 mm. It is clearly 3 to 4 times higher than the value of the rainfall received. For this purpose, the PET generates a water deficit (drought) and/or favors a considerable influence on the soil and the growth of vegetation in the steppe ranges. In this steppe area of Naâma, the average annual precipitation is less than two thirds of the potential evapotranspiration (potential evaporation from the

ground plus transpiration by plants). The high evapotranspiration confirm the climate aridity of the study area.

The vegetation can have an impact on the water balance by increasing evapotranspiration and reducing runoff, and the vegetation is characterized by various morphological, physiological adaptations such as xerophytes.

It is therefore easy to understand why most steppe species have low woody and herbaceous plants, and they have characteristics of xeromorphism (*Stipa tenacissima*, *Lygeum spartum*, *Stipagrostis pungens*)) and sclerophyllia, especially in phanerophytes (*Quercus ilex*, *Pinus halepensis*, *Juniperus phoenicea*, *Juniperus oxycedrus*, *Pistacia atlantica*). They have as a result low size of plants and leaves, and low gross production. These plants reduce their exchange surfaces and close their stomata.

In perspective, it is necessary to assess this component of the water balance precisely from field measurements and to establish maps taking into account the particularities of the existing vegetation. This type of study makes it possible to formulate recommendations to better understand the species adapted to these climatic rigors.

Acronyms and abbreviations

HCDS	High Commission for the Development of the Steppe
ET	Evapotranspiration
EUR	Easily Usable Reserve
MET	Maximum evapotranspiration
NMO	National Meteorological Office
PET	Potential evapotranspiration
RET	Real evapotranspiration

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