Evaluation of Thornthwaite's method to establishing a water balance in hyper-arid lands

(case of El Oued region - Southeast Algeria)

Abdennour LAMOUDI[1], Salim KHECHANA[2], Difallah Ahmed[3], Ali GHOMRI[4]

[1]Exploitation and Development of Natural Resources in Arid Zones, Research laboratory at Ouargla University (Algeria), lamoudi.abdennour@univ-ouargla.dz

[2]Exploitation and Valorization of Saharan Energy Resources (LEVSER) – Research laboratory at El-Oued University El-Oued 39000 –(Algeria), khechana-salim@univ-eloued.dz

[3]Water and Environmental Engineering in Saharan Milleau (GEEMS) Laboratory, Kasdi Merbah University, 30,000 Ouargla (Algeria), difallah.ahmed@univ-ouargla.dz

[4]LARHYSS Laboratory - Department of Civil Engineering and Hydraulics - Biskra University and Department of Hydraulics and Civil Engineering- El Oued University (Algeria)

Received: 04/2023, Published: 04/2023

Abstract :

The valley of Oued-Souf, located in the North East of the Algerian Sahara, characterized by an hyper arid climate, marked by a mild and dry winter and a very hot summer, with an average annual temperature of 23° C, translating into an excessive evaporation. The region suffers too much from the problem of rising groundwater which is the result of water excess (or hydromorphy). However, the most previous hydrological studies have shown that the water balance of the region is deficient. These observations lead us to evaluate the climatic parameters of the region and to examine the water balance established by Thornthwaite method. We have found that the soil storage capacity is not taken into account by application of this method which leads to an underestimation of the water balance, so as a mismanagement of water resources theoretically and practically.

Key words: Oued-Souf valley, hyper-arid climate, Thornthwaite method, water balance, water excess, soil type.

Tob Regul Sci. ™ 2023;9(1): 1356-1373
DOI: doi.org/10.18001/TRS.9.1.94

I. INTRODUCTION :

The climate plays an essential role in the morphology of the relief, on the vegetation, the genesis and the type of grounds and on the agricultural activities [1]. Water and land resources are under increasing pressure in many parts of the globe [2]. The Algerian climate is characterized by its great variability in precipitation and annual temperatures, this variation is mainly due to topographical irregularities and the opposite influences of Mediterranean and Sahara [3]. The climate of El-Oued is like the Saharan climate is characterized by a low rate of precipitation, high temperatures, significant evaporation and excessive solar radiation [4]. Many studies have demonstrated that the water balance (inputs and outputs) in the region is in deficit, in return, the rising groundwater has exposed in the region since decades (1980s), which is one of the problems associated with excess water [5]. The main purpose of this research is to estimate of Thornthwaite monthly water balance of El Oued during 30 years, and to evaluate the groundwater flow and soil type effect in equilibrium of water balance.

II. PRESENTATION OF THE STUDY AREA:

II.1. Geographical and economic situation:

The Oued Souf valley is located in the south-eastern of Algeria, occupied a surface of 350 000 ha with a total permanent population of over 600 000 inhabitants [6]. It characterized by a hyper-arid climate with a low rate of precipitation and an excessive temperature. It is bounded by the following Lambert coordinates system [7] as show the figure 1: • X = 275.200/322.000 • Y = 3.665.000/3.743.000

The region is known for its intensive agricultural and commercial activity. A veritable agricultural revolution has developed in recent years, encouraged by aid and support from the government, especially the development of agricultural land with date palms and potatoes [8]. The region has competing uses of water between the different users, irrigation being predominant, the socio-economic impacts are therefore major. The establishment of a detailed water balance is necessary to establish an optimal allocation scheme of profitable water among users, taking into account the spatial and temporal availability of water resources [9]. This situation has led to an increase in water needs, therefore, a greater mobilization of water resources [10].

Fig 1. Location of study area in North Africa

II.2. Geomorphology and Hydrogeology:

In absence of a recent soil map of the study area, we carried out field visits and examined the geological map [5]. We have found that the predominant facies is sand in the form of dunes with some clay intercalations, which is confirmed by the drilling logs shown that the depth of the sand layer exceeds one meter [11]. Despite the absence of surface water resources, El-Oued region has a very important reservoir of groundwater, in the form of three aquifers (figure 2): the unconfined aquifer and two confined deep aquifers [12, 13]. The groundwater resources potential is estimated at 4.91 million hm^3, distributed as follows: • Phreatic aquifer: 0.13 hm^3 • Deep aquifer: 4.90 Million hm^3 (whether 2.7 Million hm^3) from the Terminal Complex Aquifer (TC) and 2.2 Million hm^3 from the Intercalary Continental Aquifer (IC) [14].

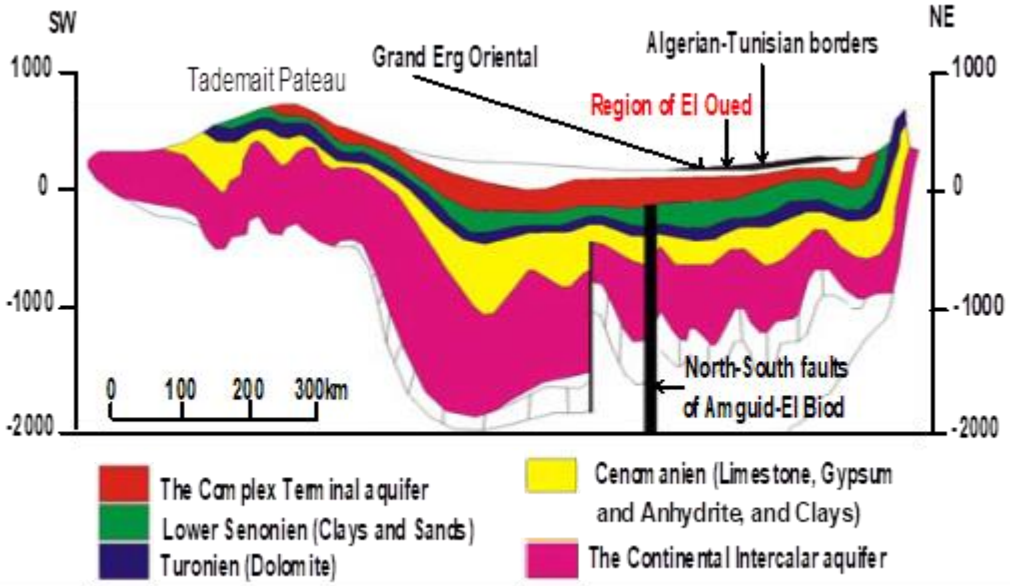

Fig 2. Geologic cross section through the Algerian Sahara showing three independent aquifer systems (Modified from Castany 1982)

III. METHOD AND MATERIALS :

III.1. Balance water :

"Water Balance" is defined as the numerical calculation accounting for the inputs to, outputs from, and changes in the volume of water in the various components (e.g. reservoir, river, aquifer) of the hydrological cycle, within a specified hydrological unit (e.g. a river catchment or river basin) and during a specified time unit (e.g. during a month or a year), occurring both naturally and as a result of the human induced water abstractions and returns [9]. According to Adam Rus Nugroho et al [15], Water balance can be defined as how much water is preserved in a water catchment area by considering how much water flows in and out of the watershed. The most widely methods to compute the balance water is that proposed by Thornthwaite and Mather [16, 17]. So, the water balance portrays the hydrological cycle quantitatively. Eagleson [18] describes water balance as a quantitative relation among long-term averages of the partition of precipitation and evapotranspiration, which are the most critical parameters. Those parameters are typically computed as average values from a time-series data set, so its equation is: P = RET + I + R ± ΔS …………………………..…….. (1)

P : Precipitation [mm], R : Runoff [mm] , R = R_{out} - R_{in}
R_{out} = Runoff as outflow from downstream of hydrologic region or rivers.

R_{in} = Runoff as inflow from upstream of hydrologic region or rivers.

I: Infiltration [mm], RET : Real evapotranspiration [mm] / RET = Evaporation (E) + Transpiration (T)

ΔS : Change in storage [mm]

If : I + R > 0 , the water balance is in surplus and there is an excess of water (EX);

If : I + R < 0 , the water balance shows an agricultural deficit (AD).

III.2. Parameters of balance water :

To establish the balance water in El Oued region and in order to measure the climatic parameters, two stations of National Meteorological Office (NMO) were selected : climate stations of Guemar and Touggourt, the first was chosen because it is the only existing station in the study area, in addition to its position at the center, the second for its nearby, its most similar altitude and whose data are the most comprehensive and representative of the study area [19], these data are chosen for a period of 30 years (September 1976- August 2006), with complete and no gaps data. Table 1 shows the geographic features of examined stations.

a. Rainfall:

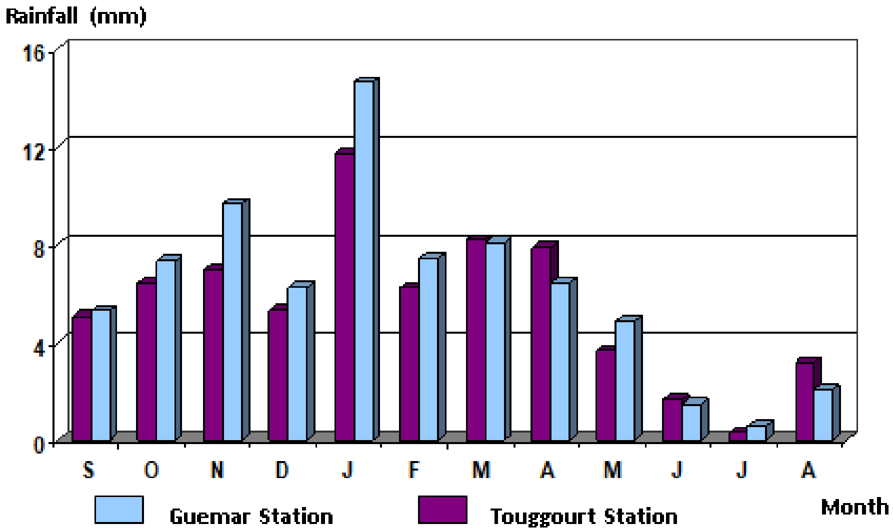

Fig.3 Average monthly precipitation in duration (1976-2006) from Guemar and Touggourt stations

Rainfall pattern is one of the most important inputs and key issues for hydrological science and practices [20], it presents a considerable interest in hydroclimatology which serves to obtain a description of the pluviometric regimes on the one hand and on the other hand its role on the flow, thus, of the global evaluation of the fallen blade of water which has an influence on the variation of the groundwater level across the study area [21]. The average monthly distributions of precipitation for a duration of 30 years for the (02) two stations summarized in Table 2 and figure 3.

Table 3 shown that :

- A high variation in rainfall with a non-constant amplitude;

- Average annual rainfall is around 73.97 mm for the first station and 66.42 mm for the second and it is very variable on the annual scale (the standard deviation is from 38.08 to 35.64 mm);

According to Dubief [22, 23], the origin of rainfall in Saharan regions is depending on the seasons: during the summer they are due to the monsoon depressions, in winter, is due to the depressions accompanying the migration towards the South of the polar fronts, and during the intermediate period, these precipitations are due to the Sudano Saharan depressions crossing the South Sahara towards the North.

b. Temperature:

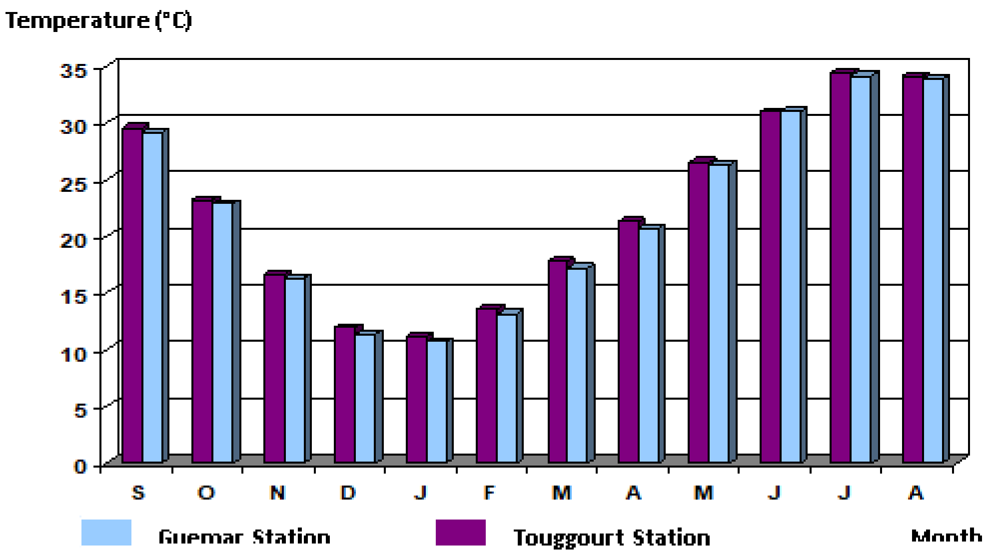

Fig.4 : Average monthly temperature in duration (1976-2006) from Guemar and Touggourt stations

The average monthly of temperature for the same duration summarized in Table 4 and figure 4.

Concerning the distribution of the temperature at the two stations in the same period, we can observe that the annual average temperature fluctuates between 22.23 °C and 22.58 °C and an annual irregularity appeared by a standard deviation between 0.71 to 0.84 °C as shows the table 5.

c. Climate synthesis:

To determine the type of climate in the region, we calculated the aridity index of De Martone (I), which is by definition: $I = P/(T + 10)$

I: Aridity index; P: Average monthly precipitation (mm); T: Average annual temperature (°C).

For Guemar station: P = 73.97 mm ; T = 22.23 °C; So: $I = \frac{73.97}{22.23+10} = 2.29\ mm/°C$

For Touggourt station : P = 66.42 mm ; T = 22.58 °C; So: $I = \frac{66.42}{(22.58+10)} = 2.03\ mm/°C$

Based on the aridity index ranges set by De Martone, we can determine the climate type of study area. Table 6 confirms that our region is characterized by an hyper arid climate.

Combination of precipitation and temperature data makes it possible to highlight the dry and wet periods during the year thanks to the Gaussen pluviothermal diagram. This diagram (figure 5) shows that the hydrological year of the study region is characterized only by a dry period and the total absence of the wet period, even for the month of January which is marked by the lowest temperature (10.67° C) and the highest precipitation (14.65 mm). Determining this period is of primary importance for irrigation water needs.

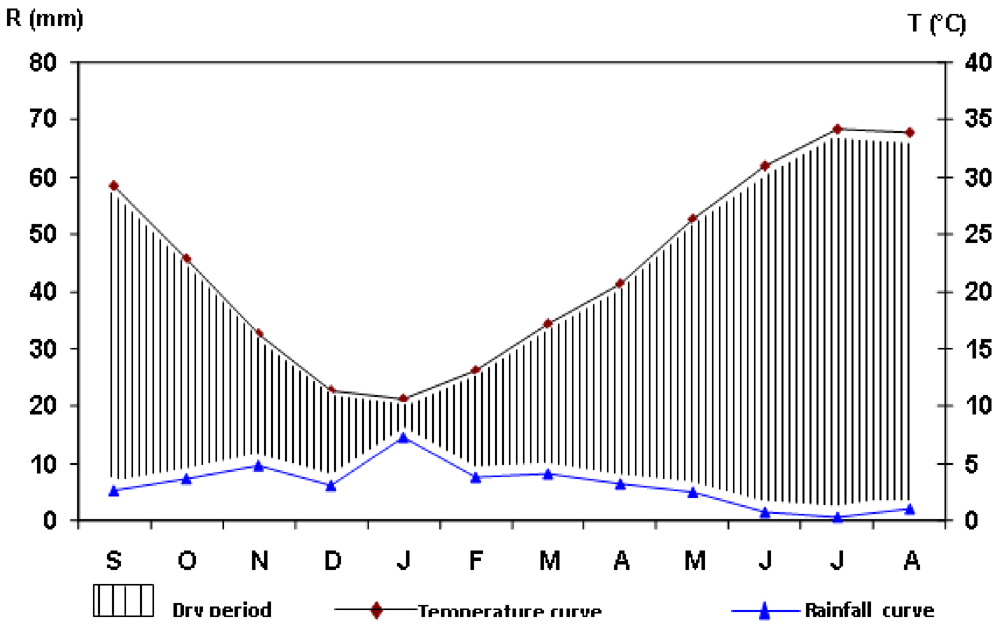

Fig. 5: Pluviothermal diagram of Guemar station (1976-2006)

d. Humidity:

Humidity is a climate state that represents the percentage of water in the atmosphere. The average humidity of El Oued region is shown in Table 7 and figure 6, where we note a minimum recorded during July with a value of around 31.63% and a maximum recorded during December with a value of 66.86%. The relative humidity is 62.83% in winter and 33.82% in summer.

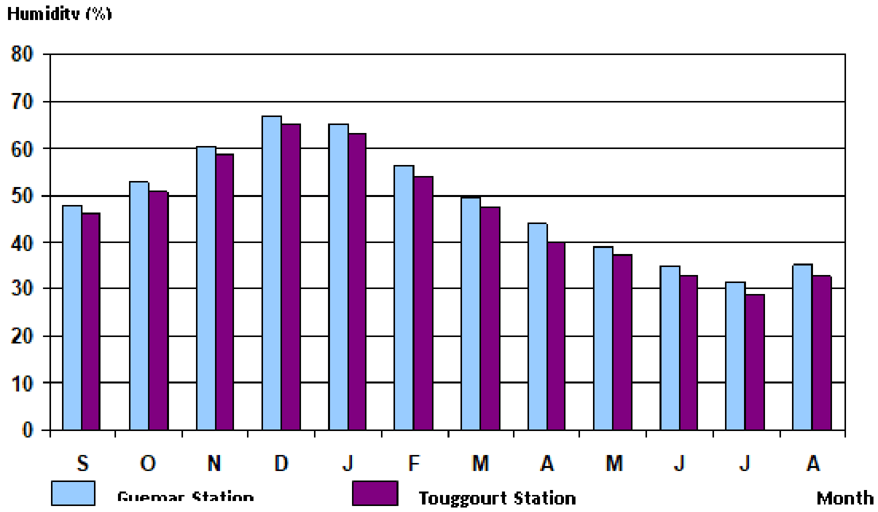

Fig.6: Interannual monthly average humidity at Guemar and Touggourt stations (%)

e. Evapotranspiration:

Evapotranspiration plays a major role for the redistribution of water on the earth's surface and it's the most significant component in the areas where the irrigation is a major component of agriculture due to low precipitation [24]. Potential evapotranspiration (PET) is the amount of water that can be returned to the atmosphere by perspiration of living being and evaporation of the soil and free water surfaces, if it permanently contains the sufficient amount of water, while real evapotranspiration (RET) corresponds to the amount of water actually transpired and evaporated.

We use the method of Thornthwaite for the calculation of potential and real evapotranspiration (PET and RET).

- **Potential Evapotranspiration (PET):**

$$\mathrm{PET} = 16\left(\frac{10\mathrm{T}}{\mathrm{I}}\right)^{a}$$

With: $a = \left(\frac{1.6}{100}\right)\mathrm{I} + 0.5$

PET : Potentielle Evapotranspiration (mm)

T : Average monthly air temperature (°C)

I : Annual thermal index

Calculation of the monthly thermal index i : $i = \left[\frac{T}{5}\right]^{1.514}$ Whence $I = \sum i$

The results are shown in table 8.

- **Real evapotranspiration (RET):**

For Thornthwaite's method, there are two main cases [17]:

1. If : P- PET > 0 ; therefore: P > PET, in this case ETR = PET.

2. If : P- PET < 0 ; therefore : P < PET, this case is further subdivided into two cases:

   a. If : P + EUS > PET $\Rightarrow$ ETR = PET.

   b. If : P + EUS < PET $\Rightarrow$ ETR = P + EUS, when EUS is Easily Usable Stock

The results of the calculations are summarized in tables 9 and 10.

f. Estimating of Easily Usable Stock (EUS):

It presents the amount of water stored in the soil, its degree of saturation depends on several factors [18]:

- The nature, the lithological composition and the thickness of the surface layer.
- The depth of the aquifer piezometric level.
- The region climate.
- The plant cover type.

We can calculate the EUS according to Hallaire's formula [24]:

$$EUS = \frac{ADS.EM.D}{3} \quad \text{………………………….. (2)}$$

EUS: Easily Usable Stock in (cm),ADS: Apparent density of soil, EM: Equivalent soil moisture.

D: Depth of the soil layer traversed by the roots (mm).

According to the Agricultural Department of El Oued [8], the value of EUS is 50 mm, this is the maximum of the Easily Usable Stock (EUS).

g. Runoff (R):

Using the Tixeront-Berkaloff formula [25], runoff can be calculated from the average annual precipitation and potential evapotranspiration: $R = \frac{P^3}{3(PET)^2}$ ……………………………… (3)

$$R = \frac{(73,97)^3}{3(1174,28)^2}$$ So : R = 0.0097 mm

It can be seen that the blade of runoff over the study area is negligible thanks to the high evapotranspiration and to the nature of soil, characterized by a high permeability, namely sandy formations [26].

Verification formulas :

1. **for Guemar station:**

- $\sum P = \sum RET + \sum EX$ …………………………………… (4)

We have : $\sum RET + \sum EX = 73.97 + 00$

= 73.97

=$\sum P$

- $\sum PET = \sum RET + \sum AD$ ……………………………… (5)

We have : $\sum RET + \sum AD = 73.97 + 1100.31$

= 1174.28

=$\sum PET$

2. **for Touggourt station:**

- $\sum P = \sum RET + \sum EX$

We have : $\sum RET + \sum EX = 66.42 + 00$

= 66.42

= $\sum P$

- $\sum PET = \sum RET + \sum AD$

We have : $\sum RET + \sum AD = 66.42 + 1116.5$

= 1182.92

=∑ PET

IV. RESULTS AN DISCUSSION :

The water balance established by Thornthwaite method for the stations of Guemar and Touggourt showed that the PET reached the maximum at July (245.61- 247.06 mm) and its minimum in January (10.34 - 10.87 mm). The establishment of the EUS is only carried out at January with a value of (4.31 - 0.87 mm) and the rest of the year is exhausted. The water balance for a period of 30 years (1976-2006) in El Oued is in agriculture deficit (AD = 1100.31 - 1114.12 mm) while the excess is zero (EX= 0).

These calculations show that El Oued region is characterized by a deficit water balance of 1100 mm, and there is no recharge of groundwater by climatic conditions, neither by runoff (R) nor by infiltration (I). These same results are demonstrated, too, by studies of Bouselsal B [27], B Khezzani and S Bouchemal [28]. But, irrigated agriculture is the largest consumer of freshwater resources in the world [28], it consumes about 88 per cent of the water resources in the region of El Oued [14]. The increase in human population and increased urbanization has demanded more water for other purposes. To compensate this agricultural deficit, resulting from a very high evapotranspiration and a low precipitation, large water consumers (domestic, agricultural and industrial users) recommend the exploitation of deep aquifers, specially, the aquifer of Terminal Complex (average depth of 200m) [10], so as in 2009, the water resources mobilized for different users exceed 1.13 km^3 and reached 1.7 km^3 in 2012 [4], this significant volume rejoined the water of phreatic aquifer and contributes directly to the problem of rising groundwater (photo 1).

Photo 01 : Excess of water appear in form of rising groundwater (Sidi Mestour El-Oued - February 2007)

Photo 2: Vegetation cover in El Oued region suppose that the stock is not exhausted

The verification formulas of Thornthwaite method (4) and (5) show that the equilibrium is recorded only between the climatic conditions (P, RET, R, I, EX and AD) and neglects the value of groundwater stock, meaning that the deficit mentioned of balance water is only registered at the atmospheric water cycle or beyond the soil surface (figure 7).

According to water balance (table 9 and 10), the value of (P-RET) is negative, results to an excessive evaporation (except during the month of January). However, the runoff is negligible (R = 0.0097 mm), so, Formula (1) Became : P-RET = I, means that I < 0, which is impossible in reality.

So, I is not only “Infiltration”, but it presents the change of groundwater flow (G) which is variable depending on the withdrawal and the recharge, so the equation (1) became:

$P = RET + \mathbf{G} + R \pm \Delta S$ ………………….. (6)

G: Groundwater flow [mm]

$G = G_{out} - G_{in}$

G_{out} = Groundwater as outflow from the hydrological basin

G_{in} = Groundwater as influx into the hydrological basin

Meaning that (G_{out}) is superior than (G_{in}), thanks to the enormous quantities of water mobilized from deep aquifers (TC and IC aquifers) which are in the same hydrogeological unit. Consequently, the deficit results from the strong evapotranspiration compensated by the additional volumes extracted from deep aquifers, resulting in an excess of water (photo 1). Sasireka K et al [29] concluded, in his studies of "Recalibration reference crop evapotranspiration" in India, that almost all the methods has overestimated they values, except Thronthwaite method which committed the highest error and Blaney-Criddle method suits better for the selected region.

Bautista et al. (2009) [30] assumed that during the rainy months, the Thornthwaite method worked very well; however, it recommended an adjustment coefficient when used during the driest months.

In our case, we find certain gaps:

The value of EUS was taken from the services of the DA [8], who estimated it by comparing values from other regions in Algeria (as Algiers, Skikda, Annaba…), and not calculated by applying Hallaire's formula (3). In this context, it noted that if the EUS formed only during January and is exhausted during other months, the plants will reach the wilting state. The opposite case which is observed, where, they are plants permanent throughout the year.

The Tixeront Berkaloff-method (4) to estimate the runoff needs only two meteorological parameters: air temperature and precipitation (because of PET is related to the T and P), is the most one used and recommended in previous studies of water balance in Algeria (the northern regions as in the south), regardless of climate type. But, this formula is lacking the influence of the soil type and its nature. It would therefore be useful to adjust the Tixeront-Berkaloff formula by a coefficient involving the significant effect of the texture of the sands characterizing the desert regions, in addition, it is essential to calculate the runoff value during the months associated with the wet season (December-January) and not through all year round (e.g. with the same formula, runoff during the month of January is:

$R = \frac{(P_j)^3}{3(PET_j)^2} = \frac{(14.65)^3}{3(10.34)^2} = 9.8$ mm) which has a big difference to the calculated mean runoff value.

IV. CONCLUSION AND RECOMMANDATIONS :

The region of El Oued located in the Algerian Sahara, characterized by a hyper-arid climate. The establishment of its water balance by the Thornthwaite method presents an agriculture deficit of more than 1100 mm per year, this is the result found by all the later studies made on arid and hyper-arid regions.

Balance water comprises all the forms of water stored under and above the earth including soil moisture, groundwater, lakes, rivers, wetlands and reservoirs. The Thornthwaite method was modified by Thornthwaite and Mather [16, 17] to make it more useful over a wide range of soils and vegetations, because of the soil has a very important impact on the water balance and it has a storage capacity that can be depleted which leads to the wilting of plants. Photo 2, which was taken during the month of June 2019, posed the assumption that the sand has a enough water storage capacity or moisture for the life of these plants. It appeared that the water balance equation is strongly influenced by the type of soil, especially when evapotranspiration is very high, the parameter which is neglected in application of Thornthwaite formula (1). In this context, we recommended to make measurements on the ground to characterize its type and the rooting of the plants to better estimate the reserve useful.

Regarding the EUS, it is very useful to find a more reliable estimate and respect more hyper arid nature and the sandy soil of the region through the implementation of some field measurements. In reality, it would probably be more interesting to study the variations in the water balance, year by year and month by month, than to give average values between years.

So, we are talking about a deficit balance at the hydrological basin characterizing a hyper-arid climate, rather balanced as a whole (figure 7), thanks to the enormous underground reservoir exploited in a wasteful manner [30]. But the fossil nature of deep aquifers (TC and IC) and their low renewal rate [12, 31] leaves us advised to treat the water of the phreatic aquifer and reuse it in agriculture and to set up a system of artificial recharge of the free aquifer and TC in areas which they undergo important drawdown.

This study may not be efficient when addressing management strategies on larger spatial–temporal scales [32], because of the study area is lacking a network of weather stations which prevents us from making a detailed study of the water balance and a good distribution of climatic parameters, but, at least, they should be changed the vision and the management of water balance and its parameter in arid and hyper-arid lands and we hope that our preliminary findings may provide policymakers with information on how to best save the groundwater resources under the conditions of global climate change for save a part of these resources to future generations. A study of the soil characteristics and measurements of the EUS are the subject of a research project in progress "URPT, University Research Project and Training" attached to laboratory research work (Exploitation and Valorization of Saharan Energy Resources -LEVSER-) of El Oued university.

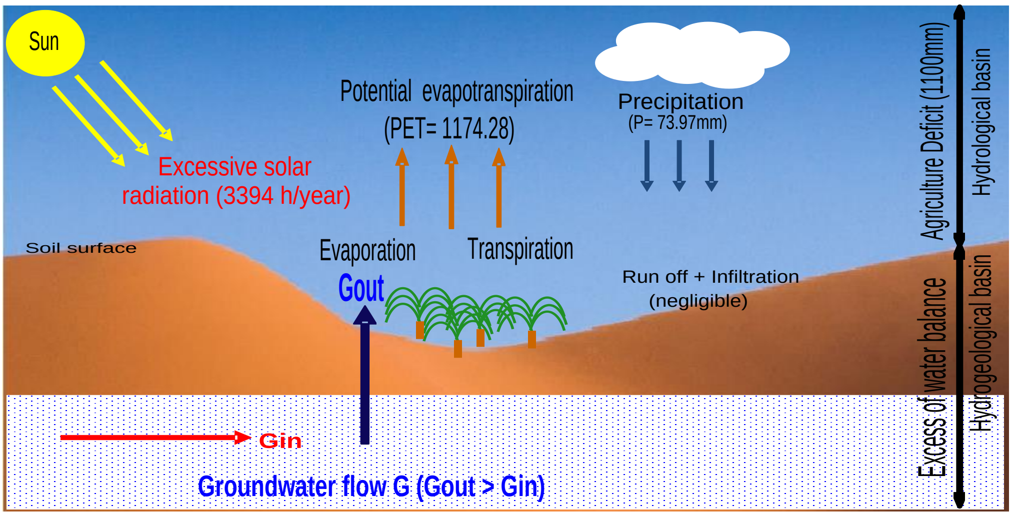

Fig 7. Deficit of water balance at the level of atmospheric water cycle-
Equilibrium of water balance thanks to enormous stock of groundwater

Tab.1 : Geographic features of examined stations [19]

Station	Altitude (m)	Longitude	Latitude
Guemar	64	06°47'E	33°30'N
Touggourt	85	06°05'E	33°04'N

Tab.2 : Monthly rainfall averages in Guemar and Touggourt stations (mm) during 1977-2006

Station	S	O	N	D	J	F	M	A	M	J	J	A	Total
Guemar	5.26	7.32	9.63	6.25	14.65	7.43	8.07	6.43	4.88	1.48	0.55	2.02	73.97
Touggourt	5,04	6,42	6,97	5,31	11,7	6,2	8,17	7,86	3,66	1,64	0,3	3,16	66.42

Tab.3 : Summary of rainfall data

Parameter	Average Rainfall (mm)	Max. Rainfall (mm)	Rainier year	Drier year	Rainier month	Drier month	Standard deviation (mm)
Guemar	73.97	78.8	1989/1990	1994/1995	January	July	38,08
Touggourt	66.42	77.9	1979/1980	1988/1989	January	July	35,64

Tab. 4: Monthly air temperature averages

Station	S	O	N	D	J	F	M	A	M	J	J	A	Moy
Guemar	29,18	22,83	16,29	11,39	10,67	13,12	17,18	20,70	26,31	31,01	34,18	33,89	**22.23**
Touggourt	29,56	23,18	16,59	11,91	11,14	13,55	17,75	21,31	26,53	30.97	34,41	34,11	**22.58**

Tab. 5 : Summary of temperature data

Parametres	Average T (°C)	Max. T (°C)	Min. T (°C)	Colder year	Warmer year	Colder month	Warmer month	standard deviation (° C)
Guemar	22.23	36.1	8.4	1990/1991	2000/2	January	July	0.84
Touggourt	22.58	36	8.3	1979/1980	2000/2	January	July	0.71

Tab.6: Classification of the aridity index (I) according to De Martonne and climate type

Aridity index	Climate
I < 5	Hyper arid
5 <I < 7.5	Desert
7.5 < I < 10	Steppe
10 < I < 20	Semi-arid
20 < I < 30	Temperate
I > 30	Wet

Tab.7: Average monthly distribution of humidity at Guemar and Touggourt stations (%) (1976-2006)

Station	S	O	N	D	J	F	M	A	M	J	J	A	Moy
Guemar	47,8	52,8	60,6	66,8	65,3	56,2	49,4	43,9	38,9	34,8	31,6	35,0	**48.6**

Touggourt	45,9	50,6	58,7	65,1	63,2	54,0	47,5	40,1	37,2	32,6	28,9	32,6	**46.4**

Tab.8: Results of the PET from the application of the Thornthwaite formula (1976-2006)

Parametre / Month	**T (°C)**		**I**		**K**	**PET (mm)**	
	Guemar	**Touggourt**	**Guemar**	**Touggourt**		**Guemar**	**Touggourt**
September	29,18	29,56	14,74	14,45	1.0	143,11	140,96
October	22,83	23,18	10,20	9,96	0.9	73,75	72,90
November	16,29	16,59	6,15	5,98	0.8	29,19	29,05
December	11,39	11,91	3,72	3,48	0.8	12,54	11,84
January	10,67	11,14	3,36	3,15	0.8	10,87	10,34
February	13,12	13,55	4,52	4,31	0.8	17,27	16,74
March	17,18	17,75	6,81	6,48	1.0	40,40	38,68
April	20,70	21,31	8,98	8,59	1.0	67,26	64,51
May	26,31	26,53	12,51	12,35	1.1	126,44	126,50
June	31,01	30.97	16.00	15,84	1.2	187,15	190,44
July	34,18	34,41	18,55	18,36	1.2	247,06	245,61
August	33,89	34.11	18,30	18,12	1.1	227,88	226,71
Total	**266,75**	**271.01**	**123,65**	**121.08**	-	**1182.9**	**1174,28**

Mois	**Sep**	**Oct**	**Nov**	**Déc**	**Jan**	**Fév**	**Mar**	**Avr**	**Mai**	**Juin**	**Juil**	**Août**	**Total**
T (°C)	29,1	22,8	16,2	11,3	10,6	13,1	17,1	20,7	26,31	31,01	34,18	33,89	22.23
I	14,4	9,96	5,98	3,48	3,15	4,31	6,48	8,59	12,35	15,84	18,36	18,12	121.0
K	1.03	0.97	0.88	0.86	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15	-
PET	140,	72,9	29,0	11,8	10,3	16,7	38,6	64,5	126,5	190,4	245,6	226,7	1174,
P (mm)	5.26	7.32	9.63	6.25	14.6	7.43	8.07	6.43	4.88	1.48	0.55	2.02	73.97
P-PET	-	-	-	-	4,31	-	-	-	-	-	-	-	-
EUS(m	00	00	00	00	4.31	00	00	00	00	00	00	00	4.31
RET	5.26	7.32	9.63	6.25	10,3	11.7	8.07	6.43	4.88	1.48	0.55	2.02	73.97
AD	135,	201.	220.	226.	221.	231.	261.	319.	441.6	630.5	875.6	1100.	1100.
EX	00	00	00	00	00	00	00	00	00	00	00	00	00

Tab.9: Water balance of Guemar station according to the Thornthwaite method (1976-2006)

Mois	**Sep**	**Oct**	**Nov**	**Déc**	**Jan**	**Fév**	**Mar**	**Avr**	**Mai**	**Juin**	**Juil**	**Août**	**Total**
T (°C)	29,5	23,1	16,5	11,9	11,1	13,5	17,7	21,3	26,5	30.9	34,4	34,1	22.58
I	14,7	10,2	6,15	3,72	3,36	4,52	6,81	8,98	12,5	16	18,5	18,3	123,6
K	1.03	0.97	0.88	0.86	0.88	0.86	1.03	1.09	1.19	1.20	1.22	1.15	-
PET	143,	73,7	29,1	12,5	10,8	17,2	40,4	67,2	126,	187,	247,	227,	1182,
P (mm)	5,04	6,42	6,97	5,31	11,7	6,2	8,17	7,86	3,66	1,64	0,3	3,16	66.42
P-PET	-	-	-	-7,23	0,83	-	-	-	-	-	-	-	1165.
EUS(m	00	00	00	00	0.83	00	00	00	00	00	00	00	0.83

RET	5.04	6.42	6.97	5.31	10,8	7.03	8.17	7.86	3.66	1.64	0.3	3.15	66.42
AD	138.	205.	227.	234.	234.	245.	277,	336,	45	645.	891.	1116	1116.
EX	00	00	00	00	00	00	00	00	00	00	00	00	00

Tab.10: Water balance of Touggourt station according to the Thornthwaite method (1976-2006)

Acknowledgements

We are very grateful to the groups of the National Meteorological Office of Guemar and Touggourt, Agriculture Department and Water Resources Directorate of El-Oued, specially Mr. Zaiz I, for the supply with complete and recent data.

Abbreviations

T Temperature

P Precipitation

IC Intercalary Continental aquifer

TC Terminal Complex aquifer

EUS Easily Usable Stock

RET Real evapotranspiration

PET Potential evapotranspiration

G Groundwater flow

I Infiltration

AD Agriculture Deficit

EX Excess water

DA Department of Agriculture, El Oued

References:

1. FAO and ITPS. 2015. Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.
2. Jalava1 M. et al., Diet change a solution to reduce water use ? Environ. Res. Lett. 9 (2014), doi:10.1088/1748-9326/9/7/074016
3. Bouchekima B. et al. The underground brackish waters in South Algeria: potential and viable resources, International Water Resources Association, XIIIth World Water Congress, 2008, France.

4. Khechana S., Perspective et méthode de la gestion intégrée des ressources en eau dans une zone hyper-aride. Application sur la vallée d'Oued-Souf (Sud-Est algérien), Thèse de Doctorat en hydrogéologie, univ. Annaba, 2014.
5. Khechana S. et al; 2016, Failure of a Vertical Drainage System Installed to Fight the Rise of Groundwater in El-Oued Valley (SE Algeria): Causes and Proposed Solutions, Journal of Failure Analysis and Prevention (JFAP) Vol 16 (02), DOI 10.1007/s11668-016-0071-8.
6. Khechana S. et al., La gestion intégrée des ressources en eau dans la vallée d'Oued-Souf : Enjeux d'adaptation d'une nouvelle stratégie. JFAS, http:// https://www.ajol.info/index.php/jfas, 2(2) 2010.
7. J.-N. Cretenet, Study of sewerage wastewater, storm water and irrigation and additional measures against the rising groundwater in Oued-Souf valley, Mission I, 2004.
8. DA, (2017), (Department of Agriculture, El Oued), Report "Agricultural areas in the Oued-Souf region"
9. Guidance document on the application of water balances for supporting, the implementation of the WFD ISBN 978-92-79-52021-1 doi: 10.2779/352735.
10. WRD (Water Resources Directorate of El-Oued), Water resources in El-Oued region, 2012.
11. National Agency of Water Resources (NAWR), Regional Directorate of Ouargla, Summary report of rising groundwater in Oued Souf region. Ministry of Infrastructure and Planning Land, National Agency of Water Resources, 1999
12. Castany G (1982) Principes et méthodes de l'hydrogéologie. Dunod, Paris.
13. Saibi H, et al, (2009) Variographic analysis of water table data from the Oued-Souf phreatic aquifer, northeastern part of the Algerian Sahara. Arab J Geosci 2:83–93. https ://doi.org/10.1007/s12517-008-0021-1.
14. S. Khechana, E. Derradji, Management of water resources in a hyper-arid area: strategy and issues (Case of Oued-Souf Valley-South Eastern of Algeria). J. Water Resour. Prot. 4(11), 922–928(2012). doi:10.4236/jwarp.2012.411108.
15. Adam Rus Nugroho et al, Thornthwaite-Mather water balance analysis in Tambakbayan watershed,Yogyakarta, Indonesia, MATEC Web of Conferences· May 2019, DOI: 10.1051/matecconf/201928005007.
16. C.W. Thornthwaite, J.R. Mather, The Water Balance, Publication in Climatology, 8, 1 (1955).
17. C.W. Thornthwaite, J.R. Mather, Instructions and Tables for Computing Potential Evapotranspiration and The Water Balance, Publication in Climatology, 10, 3, 183-243 (1957).
18. P. S. Eagleson, Ecohydrology – Darwinian expression of vegetation form and function (Cambridge University Press, Cambridge, 2002).
19. National Meteorological Office of El-Oued, "Average Daily of Precipitation and Temperature (1976/2006)" 2009.

20. Julio C. Calvo (1986), An evaluation of Thornthwaite's water balance technique in predicting stream runoff in Costa Rica, Hydrological Sciences Journal, 31:1, 51-60, DOI: 10.1080/02626668609491027.
21. Sangati, M., Borga, M., 2009. Influence of rainfall spatial resolution on flash flood modeling. Nat. Hazards Earth Syst. Sci. 9 (2), 575-574.
22. Dubief J (1947) Les pluies au Sahara central. Trav Inst Rech Sahar 6:7–23
23. Dubief J (1959) Le climat du Sahara. Travaux de l'Institut de Recherches Sahariennes, Alger
24. Catherine Jacquart et Emmanuel Choisnel, Un modèle de bilan hydrique simplifié à deux réservoirs utilisable en agrométéorologie, La Météorologie 8ème série - n° 9 - mars 1995.
25. Berkaloff, E. et Tixeront, J., Notice sur la carte du ruissellement annuel moyen en Tunisie. Etudes d'hydraulique et d'hydrologie, BIRH 1958, Secrétariat d'Etat a l'Agriculture a Tunis.
26. Drouiche. A, Impact de la remontée des eaux sur la qualité des eaux de la nappe phréatique et sur l'environnement dans la vallée du Souf Sud-Est algérien, Thèse de Doctorat en hydrogéologie, univ. Annaba, 2014.
27. Bouselsal B, Etude hydrogéologique et hydrochimique de l'aquifère libre d'El Oued souf (SE Algérie), Thèse de Doctorat en hydrogéologie, Univ. Annaba, 2016.
28. B Khezzani and S Bouchemal; Variations in groundwater levels and quality due to agricultural over-exploitation in an arid environment: the phreatic aquifer of the Souf oasis (Algerian Sahara), Environmental Earth Sciences (2018) 77:142 https://doi.org/10.1007/s12665-018-7329-2.
29. K Sasireka et al, Evaluation and Recalibration of Empirical Constant for Estimation of Reference Crop Evapotranspiration against the Modified Penman Method, 2017 IOP Conf. Ser.: Earth Environ. Sci. 80 012062
30. Bautista., F. et al. (2009). Calibration of the equations of Hargreaves and Thornthwaite to estimate the potential evapotranspiration in semi-arid and subhumid tropical climates for regional applications. Atmosphera, 22(4), 331-348.
31. Mohamedou OULD BABA SY, Recharge et paléorecharge du Système Aquifère du Sahara Septentrional, Thèse de Doctorat en géologie, univ. Tunis, 2006.
32. Y. Lei et al. How rural land use management facilitates drought risk adaptation in a changing climate - A case study in arid northern China, Science of the Total Environment 550 (2016) 192–199.