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WATER BALANCE AND CLIMATE CHARACTERIZATION OF THE MIDDLE ATLAS IN THE MOROCCO

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Abstract* — *Temperature and precipitation data from 28 stations in the Middle Atlas of Morocco were used to characterize the monthly water balance in the study area base on Thornthwaite model. Yearly AET and PET were estimated using Turc and Penman equation respectively, and the water balance and its components (runoff and infiltration) were determined for each station in the four regions. Based on the water balance parameters, climate and bioclimatic potential productivity index of each station were characterized.

Keyword s - Middle Atlas, water balance, runoff, infiltration, climate and bioclimatic potential productivity index

INTRODUCTION

Water resources are a precious asset for economic development of societies and for the satisfaction of population vital needs in terms of domestic water and food production. The geographical distribution of resources and water demands is uneven in Morocco. It is estimated that 90 % of Mediterranean climate in Morocco is arid, semi arid and extremely arid [1][2]. Humid and sub-humid areas are mainly confined in Atlas-chains and Rif Mountain. Middle Atlas, which covers an area of 23000 km2, stretches from the North of Beni Mellal to South of Taza. It was always considered as the important water reservoir of Morocco.

The importance of water flow volume and the relative streamflow regularity of rivers that rises in the Middle Atlas; such as Sebou, Oum Errabiaa and Bouregreg Rivers, as wellas Oued Moulouya, have induced public authorities to construct hydraulic water infrastructures for the domestic water supply and agricultural development.

In Morocco, drinking water production has been multiplied by 4 between 1970 and 2005.Tourism activities count for much of this increase [3][4]. Since 1950, the agricultural sector is being linear growth. Between 1993 and 2003, irrigated agricultural sector growth was approximately 4.5% per year [5], whereas it decreased by approximately 25% in the European Mediterranean countries, especially in Italy [6].

In the geographical area ofthe Middle Atlas (BeniMellal, Khenifra and Ifrane) water level and areral extent of several natural lakes (Aguelmame Aziza, Ouiouane, Aguelmama Sidi Ali, Dayet Hachellaf, Dayet Aoua...) have been constantly shrinking over the years [7][8] with all the biotic and abiotic consequences both at the ecological (biodiversity, ecological niches, local and side climate characterization) and the economic level (tourism, populations and livestock...).

During the last century a significant-increase in the temperature (0.74 °C ± 0. 18 °C) was observed at the global Level [9][10][11].This increase is linked to terrestrial climate variability but is amplified by anthropogenic activities.

The West Africa, with an increase of temperature of 0.3 to 0.7 ° C/decade over the period 1970-2004 and the largest decrease of precipitation of 7.5% per decade compared to the 1900-2005normal [12].It is estimated that arid areas have expanded over half [13].

All of these disturbances induced a changed of the surface runoff. In fact, in the Mediterranean region, a decresase in runoff and precipitation was observed during the 1971-1998 period compared to 1900-1970 [14][15] with the development of dams in some watershed[16][17].Rapid population growth is the cause of increased water stress[18][19]. According to Droogers[20] it is estimated that on the horizon 2050 available water resources in these regions, are expected to decrease approximately by 0.6 km3 each year while the total water demands could reach 393 km3/year (compared to 260 km3/year today).

Several authors believe that Morocco will be subjected to climate change both in terms of temperatures and precipitation. With an expected temperature increase (2 to 4 °C) and a reduction in in winter and early spring precipitation [21][22], what impacts will there be on streamslow of these rivers and what will be the response of forest ecosystems, particularly in the Middle Atlas.

Before addressing these questions, it seems appropriate to analysehydrological water balance based on climate data.

The physiological activity of forest ecosystems in Morocco takes place between a thermal stress in winters (temperatures decrease impose dormancy) and water balance deficit in summer which imposes a slowdown or even a growth activity cessation.

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In order to understand the hydrological and water balance, average monthly precipitation and temperature from 28 weather sites in the Middle Atlas were used. Climatic water

demand (PET), actual evapotranspiration (AET), monthly and yearly water excess and deficit and the runoff-infiltration ratio were estimated for each station. The variability of these parameters, on the basis of topographic data (altitude, exposure) and geographical position (latitude, longitude),are also discussed.

1. MATERIALS AND METHODS.

1.Study area

The study area covers the Middle Atlas (MA) which falls under four major watersheds. The area covered by the three basins (Sebou, OumEr-bia and Bouregreg) isapproximately 85 000 km2. These three rivers originate in the Middle Atlas and flow into the Atlantic Ocean. The Moulouyariver is rootedat the junction of the Middle and High Atlas, covers nearly 74 000 km2 and flows into the Mediterranean Sea.
The study area extends between latitudes 32°33' N at the South and 34°23'N to the North. The Longitude boundaries of the study area are - 6°36' W at the West and - 3°03' W to the East**Figure 1**.The geomorphological structure of the study area consists of calcareous rocksand tabular rocks to the West (altitude 1000 to 1500 m), of rocks folded in the Northeast with higher altitudes (over 3000 m) and volcanic plateaus.
In Middle Atlas, four parts are distinguished:

1. BeniMellal MA : South part of Middle Atlas;
2. Eastern MA: Northeastern part of Middle Atlas;
3. Khenifra MA: South part of Central Middle Atlas; and
4. Ifrane MA: North part of Central Middle Atlas.

2 Data used

Monthly average temperatures (minimum, medium and maximum) and monthly rainfall from 28 weather stations in the Middle Atlas for the period 1982-2012 as well as elevation, latitude, longitude and exposuredata are presented in T**able 1.** These were provided by the Forest Research Station, the Forest Services and the Directions of hydraulic and water resource. Once data homogeneity was verified, missing data were completed using published World Bank published climatic data [23] and data from [24].

3. Methods

3.1 calculation of the Potential Evapotranspiration PET

Monthly water balance was calculated for each station using Thornthwaiteequation[25]. Climate water demand PETwas corrected for latitude.
It is well known that in the Mediterranean region, Thornthwaite method underestimates the potential (PET) and the actual evapotranspiration (AET) by 10 to 30% [26][27][28],particularly in arid and semi aridareas[29][30]. However, this method has the merit of being robust, simple, using only temperature data corrected forlatitude in order to account of the duration of insolation and to track monthly water balance in the soil.

In hydrology, results of potential evapotranspiration (PET) estimates using Penman method is expected to be closer to PET established using lysimeterdata[30][31]. Due to the lack of data, the assessment of annual potential evapotranspiration was performed using Le Houérou's approach [28] which was developed using data from 196 stataion in North Africa. It is expressed follows:

$$PET = 64T \qquad (1)$$

Table 1. Geographical characteristics of the stations studied by region

Region	Station	Altitude	latitude	longitude	Exposure
BeniMellal Middle Atlas	BeniMellal	537	32,331	6,365	I (SW)
	Takbalt	700	32,449	6,000	I (SW)
	Tizi n Isly	1370	32,471	5,773	I (SW)
	Aghbala	1800	32,480	6,645	I (SW)
	El Ksiba	1050	32,569	6,034	F (NW)
	Koumch	1200	32,643	5,867	I (SW)
	El Kbab	1300	32,742	5,523	F (NW)
Khenifra Middle Atlas	Ouaoumana	727	32,764	5.726	Fl
	Kerrouchen	1350	32,803	5,325	F (NW)
	Tanourdi	2020	32,876	5,218	F (NW)
	Tafechna	1490	32,930	5,518	F (NW)
	Ajdir	1600	32,952	5,386	F (NW)
	Khenifra	870	32,998	5,655	Fl
Ifrane Middle Atlas	Tiguelmami	2100	33,100	5,051	H (SE)
	Ain Kahla	2000	33,240	5,289	F (NW)
	Azrou	1303	33,300	5,200	I (SW)
	Ifrane	1635	33,310	5.070	I (NE)
	Tagounit	1390	33,38	5.02	H (SE)
	Dayathachlaff	1760	33,545	5.001	F (NW)
Eastern Middle Atlas	Boulemane	1860	33,368	4,734	F (NW)
	ImouzerMarm	1630	33,479	4,294	F (NW)
	Skoura	1150	33,523	4,565	F (NW)
	Maghraoua	1172	33,571	4.029	F (NW)
	Bsabis	1385	33,705	4,680	H (SE)
	Ribat el Kheir	1145	33,826	4,144	H (SE)
	Tahla	582	34.05	4,417	F (NW)
	Berkine	1100	34,400	3,070	H (SE
	BabMarzouka	442	34.8	5: 32	Fl

S= South W= Western N= North E= East
F = Fresh I= Intermediate H=Hot Fl= Flat

Were T is the average annual temperature in °C.
PET estimates using this equation are 6.2 and 2% lower than those calculate by Penman and Turc equations respectively [32]. For semi arid and sub-humid areas in the African continent, a relationship between annual PET using the Penman-Monteith method and the average annual temperature was developed using data from 500 weather stations [1]. It is expressed as:

$$PET = 77.5T \qquad (2)$$

Were PET is the potential evapotranspiration in mm and T is the average annual temperature in °C.

a. **Determination of the soil Available Water Capacity AWC**

The soil available water capacity WAC is the portion of water that can be absorbed by plant roots. The AWC is function of soil depth and texture. ThusAWC varies between 70 mm for a sandy soil and 220 to 350 mm for a clay loams [28][33][34]. Thornthwaite proposed to consider a maximum AWC of 100 mm. Forest trees can get water to a depth of more than a meter and a half[35]. Water balance studies inforest ecosystems recommend an AWC of 150 to 200 mm [36][37].

In the present study we used an AWC of: (i) 75 mm for sites where annual-rainfall is less than 400 mm; (ii) 100 mm areas annual-rainfall between 400 to 500 mm; (iii) 150 mm for sites whose rainfall varies between 500 and 700 mmand,(iv) 200 mm for areas with annual rainfall greater than 700 mm. Indeed, rainfall is a determinant factor of pedogenesis. This choice is also justified by, the non-integration in our study of the snowfall, due to lack of data.

TheAWC consists of 60% of the Reserve easily usable (RFU) and the Reserve useful for plant survival (RUS = 40 % of AWC)[37].Piedallu and al. [37] used the term useful precipitation, which is a function of the interception coefficient**I**(**P = P * I**) and evaporation of the sub floor and the soil (estimated approximately to 2.5% of the PET). In the absence of interceptioncoefficient forforest ecosystem in Morocco and knowing that the ground recovery of the tree crowns is generally low to medium (< 50%), we have considered the rainfall depth (P) observed in the stations.

The soil water contenent(SWC) for a given month (n) is a function of the AWC and actual Evapotranspiration (AET) of the previous month.For a given month (n), the potential soil water content (SWCp) is the sum of the monthlyrainfall depth (Pn) and soil water reserves at the end of the previous month (n-1) with AWC as maximum value.

$$SWCp(n) = P\ (n)\ +\ SWC\ (n-1)$$

The term SWC (n-1) is equal to [P (n-1) – AET (n-1)].

The starting month is January which is SWC is at is maximum. For this month, it is considered the maximum useful reserve and we have:SWCp (January) = P + AWC (January).

This represents the available water for forest stand during the whole month.Negative values of the balance will be considered equal to zero.

b.Determination of Actual Evapotranspiration (AET)

The water balance in the soil is the difference between the inflow and outflow. Inflow is the sum of all types of precipitation (rain, snowand occult) in addition to capillarity and lateral flow (runoff and drainage) which can have a significant and beneficial for forest stand. Outflow, which represents AET, consists of forest transpiration, precipitationinterception, and soil and forest (herbaceous or woody)evaporation.

AET is estimated using PET and the amount of available water in the soil.

If PET is < Available water: AET = PET.

If PET >soil watercontent: AET = SWC.

If monthly precipitation is < PET than: AET = PET * SWC/AWC

SWC is the sum of (P - AET) and the residual water from previous month limited by AWC.

Annual AET usingTurc formula is given by

$$AET = \frac{\mathrm{P}}{\sqrt{0.9 + \left(\frac{\mathrm{P}}{\mathrm{L}}\right)^2}}$$

P is the annual rainfall in mm and L = 300 + 25 T + 0.05 T^3, where T is the average annual temperature in °C.

c. Waterflow in the soil

Lateral runoff and infiltration can happen only once the soil is saturated and that there are additional watersupply (precipitation).

Runoff is estimated using TixeronBerkaloffequation [38] [39][40] which is follow:

$Rs = P^3/3 * (PET)^2$

$$Rs = \frac{P^3}{3PET^2}$$

Where,

Rs = runoff in mm,

P = annual precipitation (mm); and

PET = annual potential evapotranspiration (mm).

The infiltrated water (**I**) will be equal to:

$$\mathrm{I}=[P - AET + (SWC - AWC)] - Rs$$

RESULTS

1. Monthly soil water balance

During the months of February, March and April, the soil saturation rate is 100% (SWC =AWC) and this is for all the considered stations. It is the same for the month of January except for Khénifraand Berkine stations where the rate is 80% and 87% respectively. These months are relatively the rainiestwith relatively low temperatures and low Potential Evapotranspiration (PET).

At the end of December, the ration SWC/AWC is on the average 82% and varies between 38% (Khénifra) and 100% (BeniMellal, Kerrouchen, Ouaoumana, Ajdir and all IfraneMiddle Atlas stations except Tiguelmamineand Tagounitwhere the average is 75% and 91% respectively.

The month of May presents an average saturation rate of 91% (all stations combined). It is 84; 87; 97 and 100%, for BeniMellal, Eastern Middle Atlas,Khenifra and Ifrane (tabular Middle Atlas) respectively. In May, the soil is also saturated in Tafechna, Boulemane and Ribat El Kheir stations. In the Ifrane MA and Tafechnastations, the abundance of precipitation is during the winter and spring while stations located in Eastern MA, we have a seasonal rainfall regime (spring-winter-autumn - summer).

At the end of June, the saturation rate is on the average 52% and fluctuates between 9% (Takbalt) and 86% (Ifrane).

For all study sites, July, August and September have the lowest saturation rates which amount to 7, 11, and 17% respectively. In IfraneMiddle Atlas stations, the saturation rate during July is 31% compared to 14; 7 and 5% for the Eastern, Khenifra and BeniMellal MArespectively.

At the end of October, all regions have an average saturation rate ranging from 29 to 37%. The maximum rate (50%) is observed inAzrou and Bsabis stations, and the minimum (21%) inTiguelmamine.

At the end of November, the saturation rate is on average 49% inBeniMellal and Khenifraregions compared to 51 and 62%, in the Eastern and Ifrane parts of the Middle Atlasrespectively. The minimum values are observed inAghbala (2%), Khenifra (24%), Tiguelmamine (36%) and Bab Marzouka (39%).

2. Potential and Actual Evapotranspiration

2.1Monthly PET and AET according to Thornthwaite

Evapotranspiration rates depend on moisture availability and the energy to vaporize this moisture as weel as the wind for moisture transport. The PET is a climatic parameter that expresses the water demand. It is a function of latent energy of vaporization. The later depends on the astronomical duration of day and the sunshine duration. The topographic parameters such as altitude, exposure and slope affect temperature and consequently,the magnitude of PET.

Calculated PETvalues are low during the cold season. All stations combined, calculated PET is 14 mm for the month of

January, 17 mm for December and February and 29 and 32 mm for November and Marchrespectively. December, January and February PET represents 2% of the total annual compared to 4% for November and March and 6, 8 and 9% for April, October and Mayrespectively. The period lasting from June to September account for 63% of the annual PET. The annual PET is on average 802; 776; 770 and 681 mm for BeniMellal, Khénifra,Eastern Middle Atlas and IfraneMiddle Atlasrespectively. The maximum PET annual values are observed in BeniMellal (933 mm), Bab Marzouka (946 mm), Ouaoumana (893 mm) and Tafechna (756 mm). The Tiguelmamine station located at 2100 m presents the lowest PET (562 mm). Tanourdi located at 2020 m altitude in Khenifra region shows a value of 590 mm.Boulemane located in the Eastern Middle Atlas (1860 m) has aPET of 673 mm. InBeniMellalMA, the minimum is 709 mm per year observed in Aghbala station located at 1800 m.

The correlation coefficient between the annual PET and elevation is -0.84, which is highly significant (0.01). In contrast the correlation coefficients between annual PET and latitude and longitude are-0.04 and-0.19 respectively and are not statistically significant.

Actual evapotranspiration (AET) is aneco physiological parameter that is conditioned by the temperature and the activity of vegetation. Thus, during the cold season, the reduced temperature stops growth activity (dormancy). However, during summer season, the non availability of water in the soil induces the closure of the stomata which explains low values of AET. AET would be then a good indicator of the growing season for forest stands.

All stations combined, the lowest values of the AET are observed in August which represents 2% of annual value compared to 4% for December, January and February and 5, 6, 7% and 8% for July, September, November and Marchrespectively. The cumulative AET value for the months of April, May, June and October represents 58 % of the annual AET. In terms of region, AET of the month of July represents 13 % of annual AET value inIfrane (56 mm) compared to 1 to 2% for the three other regions (3 to 10 mm). AETfor March accounts for 10% inBeniMellal and Eastern Middle Atlas compared to 8 and 6% for Khenifra and Ifrane MArespectively. June contributed to 13% ofthe annual AET in BeniMellal and Eastern MAregions compared to 20% and 21% for those of Khenifra and Ifrane MArespectively.

Depending on the magnitude of the monthly AET, the growing season of forest stands in the Middle Atlas would take place between March and June with a second period in October-November for BeniMellal, Khenifra and Eastern MA. These two periods,accounts for75 to79% of the annual AET in these regions compared to 75% inIfrane MA for the periods April-July and September-October. This difference is explained by the late cold season and the availability of water in the IfraneMA. In other regions, the early increase in temperature starting in March and the non availability of water in the soil starting in June (relatively less intense in the Khenifra region) would explain the difference with the tabular Middle Atlas.

Annual AET is on the average 337; 344; 418 and 447 mm inEastern MA, BeniMellal, Khenifra and Ifrane MArespectively. The minimum value is observed inImmouzzerMarmoucha station (256 mm) compared to 517 mm as a maximum value observed inAinKahla station. Correlations between AET and altitude, latitude and longitude are very weak and insignificant (0.09, 0.02 and-0.10).

2.2.PET and AET according to Turc Penman formula

On the average for all stations, the annual AET calculated using the Turc method gives 125% higher than Thornthwaite annual AET estimation. It isa 117%, 124% and 134% higher for Ifrane, Khenifra and Eastern MA and BeniMellal MA respectively (**Figure 2**). In AinKahla and Ifrane stations, annual rainfall is equal to the Penman PET. Tiguelmamine and Tanourdistations whose altitude exceeds 2000 m have the lowest PET.

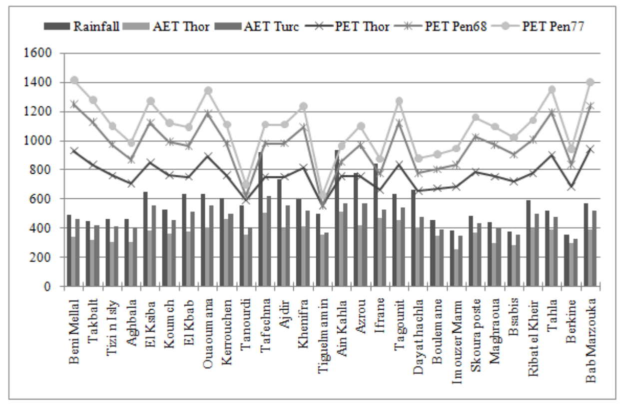


Figure 2. Annual Rainfall, actual evapotranspiration (AET) and potential evapotranspiration (PET) according to Thornthwaite (Thor), Turc and Penman (Pen68 where PET=68.64T and Pen77 where PET = 77.5T) per station. All terms are in mm/year

On the average Penman PET(calculated using PET = 68, 64 * T and PET = 77, 5 * T)values are 126 and 142% respectively higher than those of Thornthwaite. The lowest values are observed in Ifrane MA(119 and 134%) compared toBeniMellal MA (130 and 147%). Khenifra MA and Eastern Middle Atlas have substantially the same values (127 and 144%)

3. Monthly water deficitaccording to the Thornthwaite method

Water stress, which is mandatory for treegrowth is the result of an imbalance between the tree water requirement, which increases with higher temperature, sunlight and wind speed during summer season and available water which depends on precipitation during vegetation season and the accumulated stock of water in the soil during the rainy season (winter, spring).

To meet its water requirements, the plant first uses the precipitation of the month. If the precipitation is sufficient, there is no water deficit and AET is equal to the PET. In the contrary, the plant will take a certain amount of water from the soil which is a reservoir whose capacity is initialized at AWC. In thiscase, there is a water deficit and the transpiration (AET) is equal to the sum of precipitation of the considered month and what was uptake from soil reservoir during the month[41].The monthly water deficit WD is:WD = PET - AET

The periods from January to April and November to December show no water deficit. During these months soil saturation and / or low temperatures make PET and AET have the same values. It is the same for the month of May except forBeniMellal, Bsabis, ImmouzzerMarmoucha and Takbaltstations where water deficit is 15, 5, 4 and 3 mm respectively. IfraneMA stations show no water deficit during the month of June.

The months of July - August are the highest water deficits with an average of 126 to 127 mm. Temperatures increase the magnitude of the PET. The lack of water in soil in relation to the low rainfall in summer caused the closure of the stomata which explains lowAET values. The maximum for the two months was observed at Bab Marzouka station (180 and 171 mm) followed by Tahla (170-161 mm) and BeniMellalstation (167-152 mm).

The lowest water deficit values in July and August were observed in the tabular Middle Atlas stations (with the exception of Azrou) and at Tanourdi station whose altitude exceeds 2000 m.

Annual water deficit ranges between 458 mm inBeniMellal MA and 233 mm inIfrane MA. It is around 433 mm in Eastern MA and 370 mm inKhenifraMA. The water deficit during July-September period represents nearly 81% of the annual deficit inBeniMellal MA and Eastern MAcompared to 89% in KhenifraMA and 98% inIfrane MA.
The annual water deficit decreased with an increase in altitude and the correlation coefficient isaround -0.79. For latitude and longitude, correlations are statistically non-significant.

4. Excess water

Excess water is considered as the difference between the P precipitation and PET taking into account soil saturation. When precipitation occurs, it will first meet the climate demand for water before filling the water reserve. The water surplus (P>PET) will generate runoff (runoff andinfiltration), which are the hydrologicwater surplus(once saturated soil SWC = AWC).

4.1 Excess water P-PET

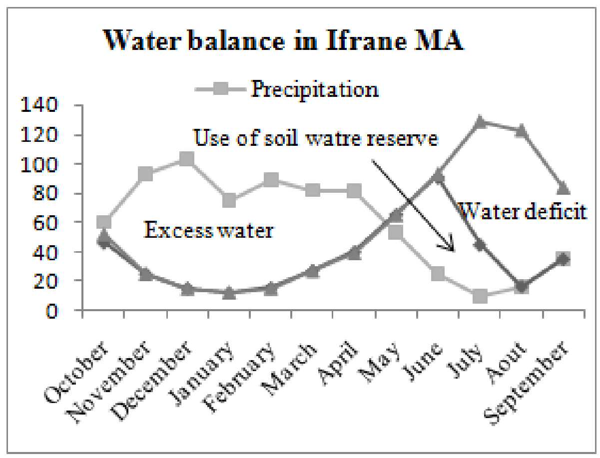
DuringJune-Septemberperiod, the P - PET difference is negative for all stations and therefore, there is no excess water during this season. It is the same for the month of May except at AinKahla and Ifrane stations with a small excess of 6 and 4 mm respectively. During October, there is lack of excess water in BeniMellal MA, Eastern and Khenifra MA except for Tafechna station (3 mm). AinKahla, Azrou and Ifrane stations show a water excess in October of 17, 23 and 43 mmrespectively.

November to March period represents the bulk of excess water. The annual excess water is on the average 305 mm and it is 190, 255, 372 and 403 mm for Eastern MA, BeniMellalMA, Khenifra and Ifrane MA respectively.

The occurrence of excess water from February to April and November to December indicates that there is an opportunity to improve biomass production through the introduction of adapted species to cold that will relieve the pressure of the pasture, specifically during this period known as a critical season.

As a conclusion, the graphical representation of the water balance in the Middle Atlas regions(**Figures 3)** shows that:

- ✓ Excess water period extends from late October until April for Benimellal MA,Khénifra and Eastern MAand until May forIfraneMA ;
- ✓ Monthly excess water is less than 60 mm and 80 mm forEastern MA and BeniMellal MA respectively. It is, however greater than 70 mm and 80 mm forKhénifraMAand Ifrane MA respectively. It may evenexceed100 mm for certain months.
- ✓ The soil stored water allows plant activity during the months of May and June for BeniMellalMA and Eastern MA and even July for the two other regions. The maximum stored water is observed inIfrane MA and the minimum in Eastern MA.
- ✓ Water deficit started at the end June for BeniMellaland Eastern MA and late July for the other regions. It is relatively less pronounced in Ifrane MA compared to the other regions



4.2. Hydrologic excesof water [P-PET+ (SWC – AWC)]

The averagedannual hydrologic water excess is 231 mm with a maximum of 453 mminAinKahla station and a minimum of 55 mm inBerkine station. In terms of regions, hydrologic excess is on the average 130, 181, 259 and 294 mm for Eastern, BeniMellal, Khenifra and Ifrane Middle Atlasrespectively. It represents on average 27, 34, 37 and 39% of the annual rainfall for Eastern,BeniMellal, Khenifra and Ifrane MA respectively. The lower percentage is observed inBerkinestation (15%) and the higher inAjdir station (52%).

Hydrologic excess water represents nearly 70% of excess water for all regions. The largest percentage (87%) is observed in Ajdir station compared to minimum of 44% in Kerrouchen station.

4.3 Runoff and infiltration

Runoff is the excess water that flows laterally (runoff) or into the soil (infiltration). It is well known that Thornthwaite method under estimatesPET and AET, and gives unconsistent results. Indeed, this method overestimated runoff and infiltration in station with less rainfalland with negative infiltration values for station with high rainfall[42]. Lebourgeoisstudies [26]reported thatThornthwaite method under-estimated PET by more than 100 mm. The same results (with some differences) were obtained when using Penman PET (PET = 68.64T).

Runoff and infiltration were calculated using Turc (AET) and Penman (PET = 77.5T) methods. These methods are well known and used successfully in estimating water balance parameters[43][44][30].Based in Turc-Penman model, estimated annual hydrologic excess water averaged 109 mm and varies between 26 mm in Berkine and Beni Mellalstations and 359 mm inAinKahla station. The estimated hydrologic excess water is 214, 149, 64 and 47 mm for the regions of Ifrane, Khenifra, BeniMellal and Eastern Middle Atlasrespectively. These estimated values for BeniMellal and Eastern MA are 36% more than the calculated hydrologic excess water using Thornthwaite method compared to 58% and 73% for the Khenifra and Ifrane MA respectively.

Estimated runoff and infiltrated were 161and 53 mm for Ifrane MA; compared to 98 and 51 mm for the Khénifra MA, 38 and 26 mm for the BeniMellal MA and 29 and 19 mm for Eastern MA. These results are to be taken with caution if we consider precipitation (effective rainfall, rainfall distribution and intensities, and even the type of precipitation). Indeed, stations located in high elevation receive significant amounts of snow that will improve their water balance. Structural. parameters controlled by geological and tectonic features (lithology, karstification, fracturing) and the soil (soil type, depth and compaction) affect greatly water flow and infiltration ratio [45][46].

The infiltration rateis on the average 6% for all stations. Infiltration rates are 4% in Eastern MA, 5% in the BeniMellal MA and 7% at the Khenifra and Ifrane MA.

Figure4 Shows the magnitudeof infiltrated water (**I**), lateral runoff (**Rs)** and hydrologic water excess (**I + Rs**).

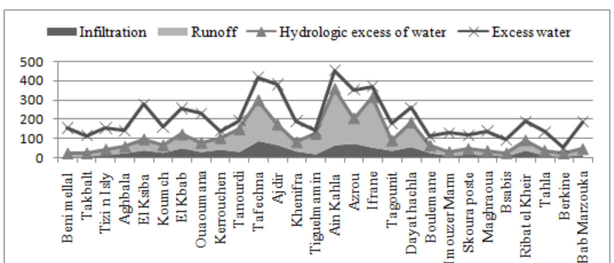


Figure 4. Annual Infiltration, Runoff, Hydrologic and Excess water in mm per station.

5. Bioclimatic zoning

Indices have been developed to delineate the bioclimatic zones and to explain the vegetation geographical distribution [47]. Among these indices, one can cite precipitation and potential evapotranspiration ratio(P/ETP) [48] [49], Actual evapotranspiration and Potential evapotranspiration ration (AET/PET)[27]and bioclimatic potential index (**IPB**) [50]. The later considers five potential productivityclasses.

$$IPB = AET\sqrt{(AET - \Delta)}$$ Where Δ = PET – AET

The zoning established using P/PET ratio and AET/PET ratio is shown in **Table 2.**

Areas	P/PET		AET/PET	Bioclimaticpotentialproductivity Index	
	Penman	Thomthwaite		IPB	Productivitypotential
Semi arid	0.28-. 43	0.21 - 0.50	0.1 - 0.25	> 600	Exceptional
Sub-humid dry	0.43-. 60	0.51 - 0.65	0.25 - 0.45	599 500	Very high
Sub-humid and humid	0.60-. 90	> 0.65	0.45 - 0.6	499 450	high
Hyper humid	> 0.90		> 0.6	449 400	Medium
				399 290	low

Thornthwaite index distinguishes two bioclimatic zones: the dry sub-humid bioclimate which includes BeniMellal, Takbalt,Tizi n Islyand Eastern MA (except
Boulemane and Ribat Al Kheirstations). The other stations have a humid and sub humid bioclimates. The calculated P / PET ratio using Penman-Turcmodel classifies the studied stations in four bioclimates zones.

1. Semi aridbioclimate: The concerned stations areBeniMellal, Takbalt, Tizi n Isly and those of Eastern MA (except Boulemane and Ribat Al Kheir);
2. Dry sub humid bioclimate, which includesBoulemane and Ribat Al Kheir as well as Aghbala, Koumch, El Ksiba and El Kbab in BeniMellal MA, and Ouaoumana, Khénifra and Kerrouchen stations inKhénifra MA, and TagounitinIfraneregion.
3. Subhumid and humid bioclimate: Ajdir, Tanourdi and TafechnainKhénifraMA and three stations in the Ifrane MAnamely:Azrou, DayatHachlaff and Tiguelmamine.
4. Hyper humid: it is the case of Both AinKahla and Ifrane stations.

The Evapotranspirationsratio calculated usingThornthwaite and Turc-Penman methods shows the similar results for 20 stations out 28. Thus, BeniMellalMA stations (except El Kbab and Koumch) as well as Eastern MA (except Boulemane and Ribat Al Khéir) are classified as sub humiddry bioclimatic zones. Ifrane MAstations (except Tagounit and Azrou) as well asTafechna and Tanourdi stations have a moist hyper humidbioclimate. El Kbab, Ajdir, Azrou,Kerrouchen and the Ribat Al-kheir are located in the subhumid to humid. For The rest of the stations, the high Thornthwaitecalculated ratio classifies them in the subhumid dry while Turc-Penman model places them in the subhumid humid.
According to the bioclimatic productivity potential index, there are five classes:

i. Stations with very high potential: Ifrane, AinKahla and Tafechna;
ii. Stations with high potential:Ajdir and Azrou;
iii. Stations with mediumpotential:Kerrouchen, Ouaoumana, Tagounit, El Kbab, El ksiba and DayatHachellaf;
iv. Stations with low potential: Tahla, Aghbala, Boulemane, Koumch, Bab Marzouka, Tiguelmamine, Ribat Al Khéir, Khenifra and Tanourdi;and
v. The rest of the stations that have a very low bioclimatic potential.

CONCLUSION

Thornthwaite model for studying monthly water balance has the advantage and the merit of being simple, robust and requiring only temperature data which available in thestudy area. While underestimating the magnitude of actual and potential evapotranspiration, this method helps to understand the water balance. However, this model shows its limit when taking into consideration runoff and infiltration. Turc method for calculating the annual AET gives better results than those using Thornthwaiteor Penman methods. The use of water balance parameters calculated by the Turc and Penman methods is more appropriate to apprehend the water balance.

Water balance analysis in four regions of the Middle Atlas (MA) shows that:

- Excess water period extends from late October to April for three regions (BeniMellal MA, Khénifra MA and Eastern MA) and May for Ifrane MA region.
- Monthly excess is less than 60 and 80 mm per monthin Eastern MA andBeniMellal MA respectively. It is greater than 70 and 80 mm per month inKhénifraMA andIfrane MA respectively. It caneven exceed 100 mm for certain months. The occurrence of excess water from November to April indicates that there is opportunity to improve biomass production through the introduction ofcold species adaptedthat will help take the pressure of the pasture, especially during the period between the end of the pasture of the harvested fields and the appearance of the grass coverinspring season.

The soil water reserve allows a plant activity during the months of May - June for theBeniMellalMA and Eastern Ma and until July for the other two regions. The maximum water reserve is observed in Ifrane MA and the minimum in Eastern MA.

The annual excesswater is on average 47 to 214 mm for the four regions. The infiltration rate is about 4 to 7% depending on the region.

Estimated runoff in the Middle Atlas ranges from 29 to 161 mm which represents 6 to 21% of the annual rainfall. These results could be improved if snow data were avalaible. Geological, tectonic and soil characteristics have a significant impact on the runoff infiltration ration.

Water deficit was observed by the end of June inBeniMellal and Eastern MA, and late July for other regions. It is less pronounced inIfrane MA compared to other regions.

Period of occurrence and intensity of water deficit study can help specify the duration and the period (s) of occurrence of forest stands growing season. Altitude, topography, climate parameter and the integrator of rain and thermal conditions, have a significant impact onwater balance parameters.

The use of bioclimatic indices base on water balance parameters, can help characterizes climatic and bioclimatic potential of each studied station. These results should be confronted with the conventional characterization approaches.

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