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Evolution forecasting of the reference evapotranspiration under the impact of climate change in the province of Ifrane (Morocco)

Labaioui A. (1) **and Razouk R.**(1)

amal.labaioui@inra.ma

1: Regional center of agricultural research, Meknes, Morocco.

Abstract

Climate change presents new challenges for agriculture. When it comes to planning adaptation measures, estimating the crop water requirement plays a key role. In the water cycle, evapotranspiration accounts for around two-thirds of the volume of exchanges, and its estimation is important for irrigation scheduling, water resources planning and management. The reference evapotranspiration (ET_0) defines the potential evaporation of a standard vegetation cover with plenty of water. It is calculated using several models, including that of Jensen and Haise, used in this study to predict the evolution of the ET_0 by 2050 in the province of Ifrane (NW Morocco). To do this, the current and future monthly mean air temperature from the Miroc-ESM model and according to two climatic scenarios RCP4.5 and RCP8.5, were downloaded from Worlclim database. Personalized climatic layers of the study area are generated using the two software DIVA-GIS and ArcGIS. The results show that the ET_0 will increase in the future for all months and more markedly for pessimistic scenario RCP8.5, it will vary between 9 mm in January and December and 135 mm in July for the RCP8.5 scenario and between 8 mm in January and 131 mm in July for RCP4.5 scenario, against 4 mm in January and 118 mm in July currently. This highlights the need for adaptation of agriculture in the study area by mastering the opportunities and risks of climate change concerning water resources.

Key words: climate change, reference evapotranspiration, Morocco.

Prévision de l'évolution de l'évapotranspiration de référence sous l'impact du changement climatique dans la province d'Ifrane (Maroc)

Résumé

Le changement climatique place l'agriculture face à de nouveaux défis. Lorsqu'il s'agit de planifier les mesures d'adaptation, l'estimation du besoin en eau des cultures joue un rôle capital. Dans le cycle de l'eau, l'évapotranspiration représente de l'ordre des deux tiers du volume des échanges et son estimation est importante pour les programmes d'irrigation, la planification et la gestion des ressources en eau. L'évapotranspiration de référence définit le potentiel d'évaporation d'un couvert végétal standard abondamment approvisionné en eau. Elle se calcule à l'aide de plusieurs modèles, parmi lesquels celui de Jensen et Haise, utilisé dans cette étude pour prévoir l'évolution de l'évapotranspiration de référence à l'horizon 2050 dans la province d'Ifrane, pour ce faire, des données climatiques de la température moyenne mensuelle actuelle et future selon deux scénarios climatiques RCP8.5 et RCP4.5, ont été téléchargées des bases de données climatiques pour le modèle climatique Miroc-ESM. Les résultats montrent que l'ET0 augmentera dans le futur et d'une façon plus marquée pour le scénario pessimiste Rcp8.5, elle variera entre 9 mm en janvier et décembre et 135 mm au mois de juillet pour le scénario RCP8.5 et entre 8 mm en janvier et 131 mm en juillet pour le scénario RCP4.5 contre 4 mm en janvier et 118 mm au mois de juillet actuellement. Ce qui met en évidence la nécessité d'adaptation de l'agriculture dans la zone d'étude en maitrisant les opportunités et les risques du changement climatique concernant la ressource en eau.

Mots clés : changement climatique, évapotranspiration de référence, Maroc.

التغير في التبخر المرجعي في ظل تغير المناخ في إقليم إفران (المغرب)

لبعيوي أمال ورزوق رشيد

ملخص

يفرض تغير المناخ تحديات جديدة على الزراعة. عندما يتعلق الأمر بتخطيط إجراءات التكيف، فإن تقدير الاحتياجات المائية للمحاصيل يلعب دورًا رئيسيًا. في دورة المياه، يمثل التبخر حوالي ثلثي حجم التبادلات وتقديره مهم لبرامج الري والتخطيط وإدارة الموارد المائية. يحدد التبخر المرجعي إمكانية التبخر لغطاء نباتي قياسي به الكثير من الماء. و يتم حسابه باستخدام عدة نماذج، بما في ذلك نموذج جنسن وهايز، المستخدم في هذه الدراسة للتنبؤ بتطور التبخر المرجعي ET_0 بحلول عام 2050 في إقليم إفران. للقيام بذلك ، تم تنزيل البيانات المناخية لمتوسط درجة الحرارة الشهرية الحالية والمستقبلية وفقًا لسيناريوهين مناخيين RCP8.5 و RCP4.5 من قواعد البيانات المناخية لنموذج المناخ Miroc-ESM. تظهر النتائج أن ET_0 سيزداد في المستقبل، وبشكل أكثر وضوحًا بالنسبة للسيناريو المتشائم RCP8.5 ، و سيتنوع بين 9 ملم في يناير وديسمبر و 135 ملم في يوليو حسب السيناريو RCP8.5 وبين 8 ملم في يناير و 131 ملم في يوليو بالنسبة للسيناريو Rcp4.5 مقابل 4 ملم في يناير و 118 ملم في يوليو حاليًا. وهذا يسلط الضوء على الحاجة إلى تكييف الزراعة في منطقة الدراسة من خلال إتقان فرص ومخاطر تغير المناخ فيما يتعلق بالموارد المائية.

الكلمات المفتاحية: تغير المناخ، التبخر المرجعي، المغرب.

Introduction

Climate predictions converge to confirm the increase in warming and the spatio-temporal variability of precipitation. More extreme events and increased climate variability are also predicted (IPCC, 2007) and would be other components of climate change to consider. The reality of this worrying development is confirmed by increasing observations of abiotic and biotic changes (impacts) in connection with the climatic context and in particular warming. The risks incurred in terms of production are foreshadowed by the significant losses in crop production resulting from recent unprecedented climatic extremes.

Climate change impacts the water cycle and agriculture. The top five risks identified by the latest IPCC report, are related to water, agriculture and livelihoods. The risk is global, regional (Africa, Mediterranean, South Asia…), national and local (IPCC, 2015). Climate change is expected to intensify the hydrological cycle and to alter one of its important components, evapotranspiration (Huntington 2006). By 2100, researchers predict a decrease in soil water availability, mainly because of warming, and therefore an increase in evapotranspiration, but also because of the decrease in rainfall. With higher temperature, the water requirements of plants will increase (Mueller et al., 2014).

Evapotranspiration is a key variable in the hydrological cycle, it conditions soil moisture, a factor regulating the sharing of precipitation between infiltration and runoff as well as groundwater recharge. In a warmer climate, it is very likely (90-100% probability) that the reference evapotranspiration will increase due to high energy available at the surface and to an increase in air specific humidity at saturation (warmer air can hold more water vapor) (Dayon, 2015). Recent studies confirm the increasing trend of actual evapotranspiration since 1980 announced in the 5th IPCC report. It would have increased globally by +1.51mm/year over the period 1982-2009 (Zeng et al., 2014). According to Miralles et al.(2014), the tendency to evapotranspiration increase is well marked in the northern hemisphere and would reach around +0.66 mm/year over the period 1980-2011. Another study shows a trend of +0.49 mm/year worldwide. The inventory of works that determined past trends in ET_0 evolution in the Mediterranean region led to conclude that among 22 studies, 15 show an increasing trend, 3 do not show any trends and 4 report a decreasing trend(Vicente-Serrano et al., 2014b). In Spain, marked tendencies to ET_0 increase have been demonstrated (D. Aubé, 2016). In other parts of the world, research results are divided into increasing trends and decreasing trends in ET_0. Bandyopadhyay et al. (2009) reported decreases in ET_0 all over India, the same result was showed by Mojid & al.(2015) in Bangladesh. On the other hand, several researchers reported increases in ET_0 trends (Yu et al. (2002) (Taiwan), Hess (1998) (Nigeria), Milly and Dunne (2001) (North America)).

The change in the reference evapotranspiration values is mainly due to a change in its meteorological components : the radiative component (available solar energy) and the aerodynamic component (air drying power, mainly due to wind speed and atmospheric humidity)(Vicente-Serrano et al.(2014)). Matsoukas et al. (2011) reported that aerodynamic component has more importance than radiative in warm and dry regions. ET is controlled by several variables : the radiation (solar and atmospheric), wind, humidity, temperature, plant cover and available water. It would also be dependent on large-scale climatic phenomena (Douville et al., 2013). All this makes difficult its estimation and the projection of its evolution. Therefore there are great uncertainties on the amplitude of the changes, and the confidence associated with the projections is considered low by the IPCC (Mueller, al., 2014). But its estimation and the study of its evolution remains important for irrigation programs, and for water resources planning and management (Djaman et al., 2015) (Ndiaye et al., 2017).

In Morocco, in the Atlas Mountains, warming would reach between 2.2 and 3.1 ° C in 2055 depending on the scenarios, the precipitations will be reduced from 2.3 to 5.3% (6.3 to 8 % during spring) (IRES, 2013). The expected warming would disrupt the crops growth and development cycle (Guo, 2013), and increase crops water demand. It would also affect water availability through a reduction in the amount and duration of rain, not only for agriculture but also for the natural vegetation, risking to degrade biodiversity being one of the riches of mountainous areas. Forecasts state a reduction of around 60% in plant biodiversity by 2080 in the Mediterranean mountains (Lee and Huang, 2014). The present study aims to predict the ET_0 evolution by 2050 in Ifrane province located in the center of the Middle Atlas. The results will be of great interest in predicting crop water requirements. The final goal is a better adaptation of cropping systems to projected changes in the water sector.

Materials and methods

Study area

The province of Ifrane (33°32'N, 5°06'W) is located in central Morocco, at the heart of the Middle Atlas with an area of 3573 km2, it is part of the Fez-Meknes region (Figure 1). It is limited to the north by the provinces of Sefrou and El Hajeb, to the south and west by the province of khenifra and to the east by the province of Boulmane. The climate is Mediterranean, characterized by a harsh winter and a cool summer. The annual average rainfall is 600 mm with exceptional years in which the rainfall exceeds 1,300 mm. The annual average air temperature is 11.4 ° C. Land use is dominated by cereals which occupy 58% of the UAA, arboriculture, especially rosaceae, comes in third place with more than 12%, represented mainly by apple trees (66%). Other crops (market gardening, legumes, etc.) represent less than 2% each. The fallow completes the total with almost 11% of the useful agricultural area (UAA). Ifrane province is a privileged territory for fruit rosaceae. It has many advantages for the development of this sector, mainly favorable climatic conditions (Temperature and water resources). In recent years, fruit growing has developed spectacularly in the province.

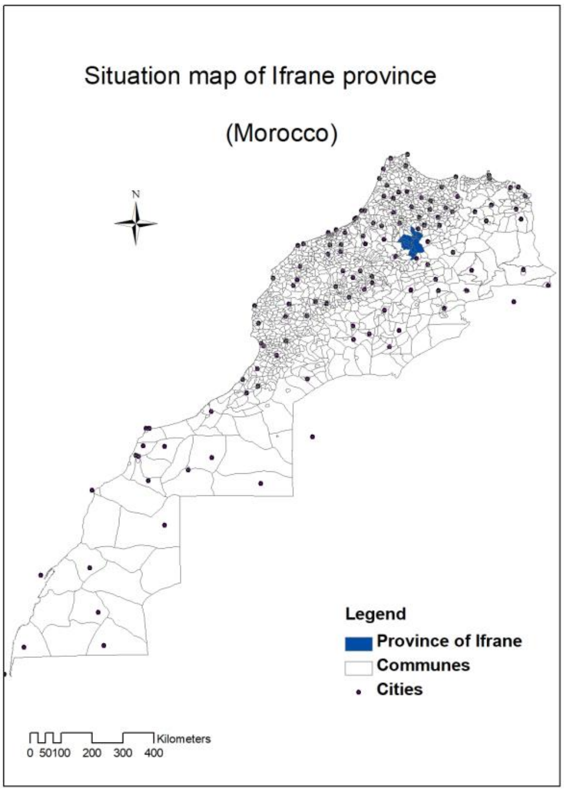

Figure 1: The geographical location of study area

ET₀ calculation

To study the evolution of ET₀ by 2050, the principle consists of comparing the current and future reference evapotranspiration according to the two climate scenarios Rcp8.5 and Rcp4.5.

The monthly ET₀ maps were generated using the climate data of monthly mean air temperature, and the ET0 estimation formula of Jensen and Haise (1963) **(Eq1),** considered the most accurate being highly correlated with the Penman-Monteith model (Ndiaye and al., 2017) (Tegos et al., 2015), and that does not require many climatic variables.

$$ET_0 = 0.0057 \times (Tm + 3) \times Rs \quad \text{(Eq1)}$$

Tm: monthly mean air temperature in ° C

Rs: monthly solar radiation in MJ/m2

- Climate Data

For the current air temperature (Reference Line), we used monthly data from the Worlclim (WC) database (publicly and free available at http://www.worldclim.org). WC provides information on interpolated global climate surfaces, using latitude, longitude, and elevation, as independent variables, and represent the long-term (1950–2000), as well as maximum, minimum, and average, without omitting the total rainfall. Input data for the WC database came from weather stations around the world, including ~

47,000 weather stations with monthly rainfall information, ~ 23,000 stations with average temperature data, and ~ 13,000 locations. By going through a quality control algorithm, the input data was finally interpolated to a spatial resolution of 30 arc seconds, commonly referred to as "1-km" resolution (Eitzinger et al., 2013). The solar radiation data are from a weather station located in Ifrane at ground level.

The projections of the future mean air temperature are the outputs of the Miroc-ESM model. We downloaded monthly time series from the site: www.ccafs-climate.org, at 30 arc seconds resolution, for the 2050 horizon according to the RCP4.5 and RCP8.5 scenarios (*Representative Concentration Pathway)*. The Miroc-ESM model is based on the global climate model MIROC (Interdisciplinary Model for Climate Research) developed in cooperation between the University of Tokyo and the Japanese agency for earth sciences and marine technologies.

These data are imported into the DIVA-GIS software to generate a current and future climate database according to the two climate scenarios RCP4.5 and RCP8.5 for Ifrane province. This database was used to create personalized maps of monthly average temperature, then exported to Arcgis to develop reference evapotranspiration maps using ET_0 formula (Eq1)

The DIVA-GIS model

DIVA-GIS is a computer program for mapping and analyzing spatial data. It is particularly useful for analyzing the distribution of organisms in order to elucidate geographic and ecological patterns. It was developed at the International Potato Center in Peru by Robert Hijmans and others collaborators, and later improved by Hijmans at the University of California, Berkeley. DIVA-GIS supports vector data types (point, line, polygon), image and grid. It can help improve data quality by finding coordinates of localities using geographic directories and checking existing coordinates using overlays (spatial queries) of collection sites with administrative boundary databases. Distribution maps can then be established. The analytical functions of DIVA-GIS include mapping the richness and diversity (including the molecular markers database, mapping the distribution of specific traits, identifying areas with an additional diversity and the calculation of the spatial autocorrelation. DIVA-GIS has a lot of features built in and can also extract climate data for a local study area using regional or global databases (Legg and Ibadan, 2007). The choice of Diva-GIS for this study is based on several criteria, including its simplicity, flexibility, compatibility with other common software and data formats, and also because it is free software.

Results and discussion

For the air temperature variable, the results of RCP4.5 and RCP8.5 scenarios show an increasing trend in monthly mean temperatures by 2050 in the study area, considering the Miroc-ESM climate model, compared to the current period. This trend is observed for all months of the year. For example, the monthly mean air temperature in May varies between 9 °C and 18 °C currently and between 13 °C and 22 °C in 2050 according to the RCP8.5 scenario **(Figure 2)**. All the projections for the twenty-first century on a global scale agree towards a generalized increase in temperatures. It will be more marked in summer when it could increase by 1.3 to 5.3 ° C depending on the climate scenarios (Aubé, 2016).

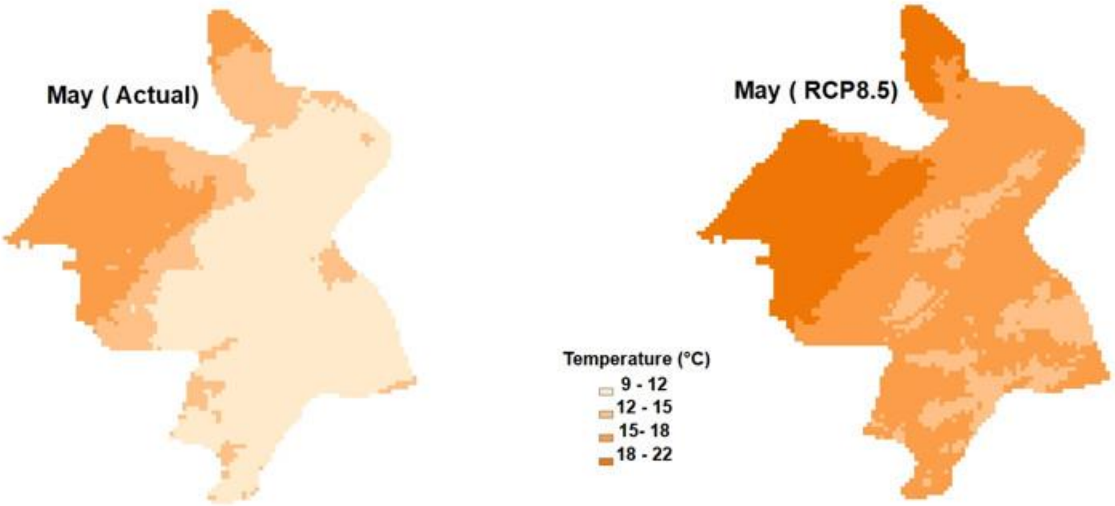

Figure 2: Mean air temperature in May at Ifrane province: actual (a) and future according to RCP8.5 scenario (b)

After the elaboration of the current and future monthly ET_0 maps based on Jensen and Haise model, and using the monthly mean air temperature maps of Ifrane province generated by Diva-GIS software, the results show that:

-In Ifrane, the highest evapotranspiration values are located in the north and north-west of the province, which corresponds to the north of the municipalities: Tigrigna, Sidi El Makhfi, Ain Leuh, Tizguite and Oued Ifrane. On the other hand the municipalities of Timahdite , Dayat Aoua and Ben Smim experience low to medium evapotranspiration values, whatever the month or the climatic scenario used (current, RCP4.5 or RCP8.5). Example given by the January evapotranspiration map according to the current (a) and Rcp8.5 (b) scenarios (**Figure 3**). Dajman et al. (2015b) confirmed that change in monthly meteorological variables in different locations might have different effects on monthly ET_0. If we consider the altitude factor, the ET in the plains is higher than in the high altitude areas.

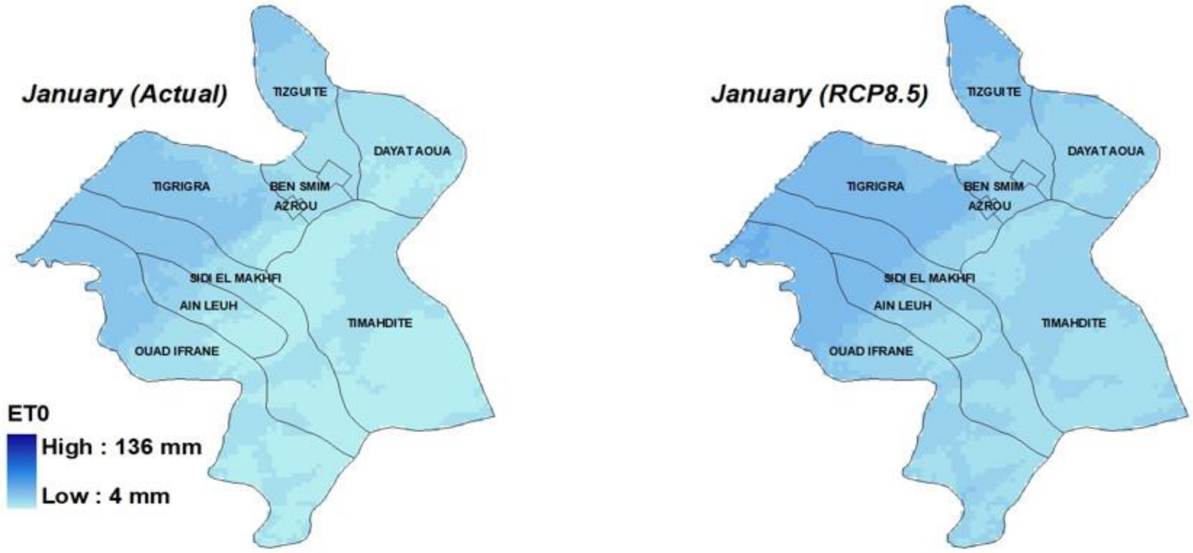

Figure 3: Reference evapotranspiration of Ifrane municipalities in January according to the current (a) and the RCP8.5 (b) scenarios

- The months of January, February, November and December mark the lowest monthly evapotranspiration values. This is explained by the low temperatures and radiation intensity recorded during these months compared to the other months. We also notice that the ET_0 increases gradually from January to the peak in July and August to then drop gradually in December **(Figure 4)**. This result is valid for the three studied scenarios. Kosa and Pongput (2007) reported that the meteorological variables, especially air temperature and net radiation, affect temporal variations of monthly mean ET_0.

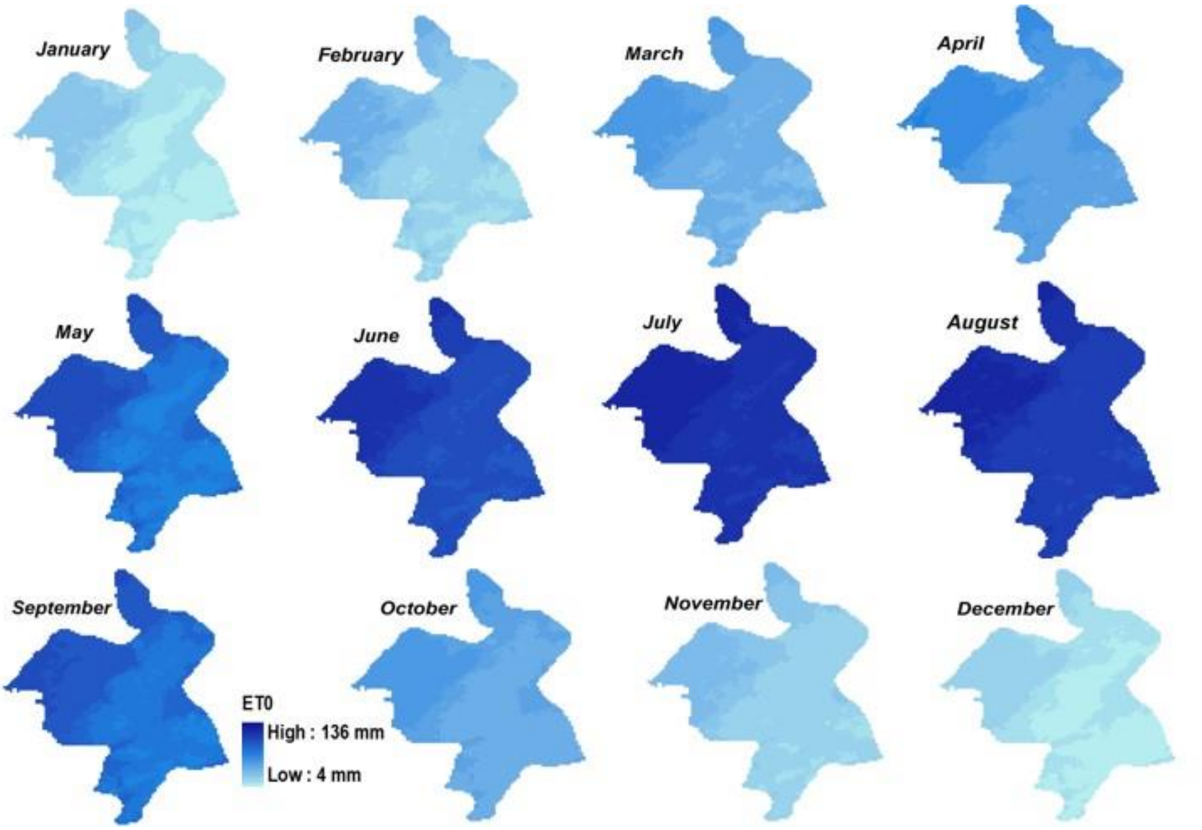

Figure 4: Monthly mean ET_0 evolution during the year at Ifrane (Actual scenario)

- When we compare the monthly evapotranspiration according to the three scenarios, we remark that this climatic variable will increase in the future and in a more marked way according to the pessimistic scenario (RCP8.5) than RCP4.5 scenario. As an example, the ET_0 values for July will vary between 112 mm as a minimum value and 135 mm for the RCP8.5 scenario and between 108 mm and 131 mm for the RCP4.5 scenario against 94 mm and 118 mm currently (**Figure 5**). We observed also that the increasing trend will concern all the municipalities of Ifrane province over all the months.

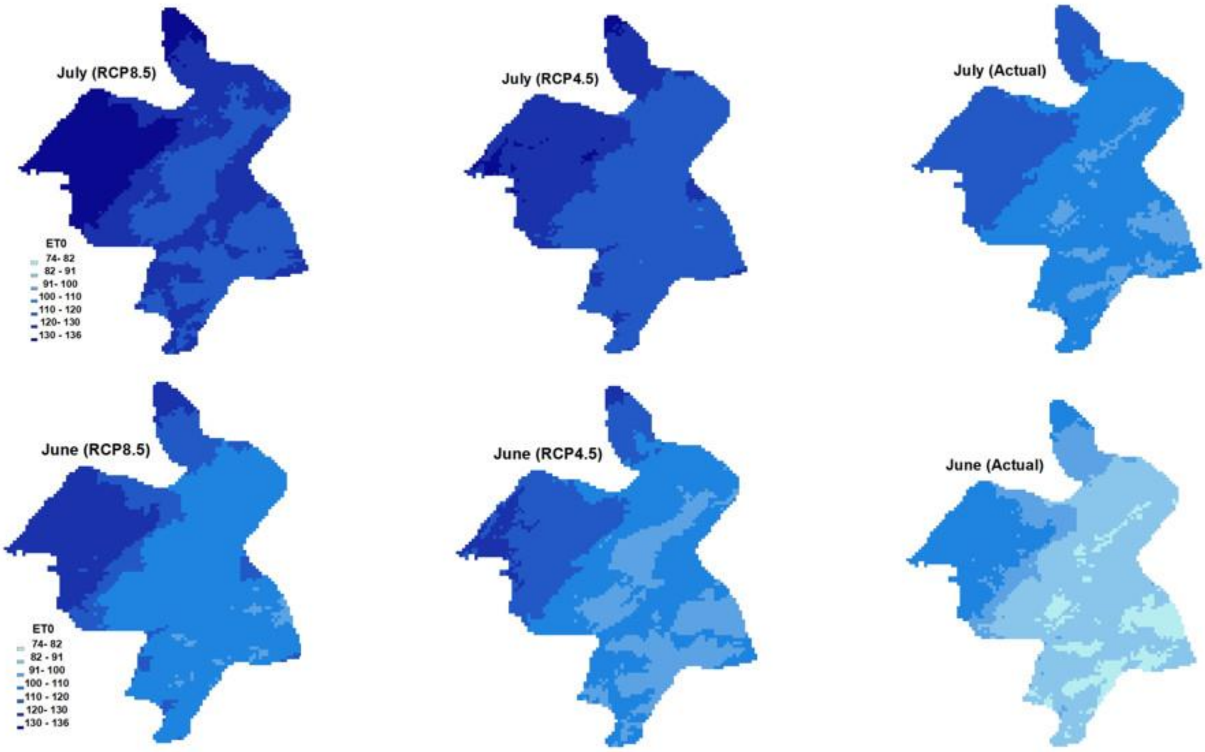

Figure 5: The evapotranspiration evolution during June and July according to the three scenarios: current, Rcp4.5 and Rcp8.5

The increase in ET_0 is greater under the higher radiative forcing scenario. In June, For example, it is nearly 21 mm under RCP 8.5 and around 16 mm under RCP 4.5. These increases are mainly due to the increase in the mean monthly temperature because it is the only climatic parameter which explains the evolution of ET_0 according to the used formula of Jensen and Haise, since solar radiation is considered stable for both current and future scenarios. The highest ET_0 increases were noted for May, June, July, August and September (**Figure 6**). These months experience the greatest increase in mean temperature.

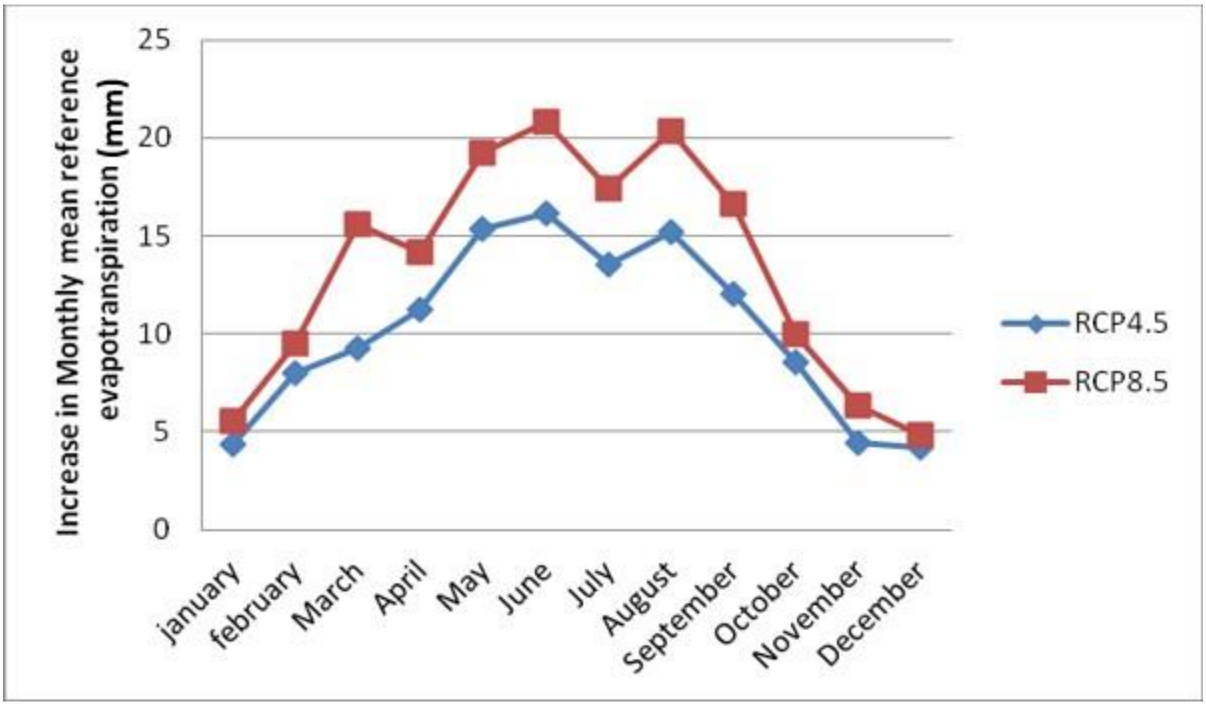

Figure 6: Future increase in monthly mean ET_0 according to the RCP scenarios

These results are in agreement with other large-scale studies on the past evolution of ET_0. Vicente-Seranno et al. (2014b) have listed all the works studying past trends in the evolution of ET_0 in the Mediterranean region, the results varied between positive and negative trend. Other studies show marked trends towards an increase in ET_0 in Spain (D. Aubé, 2016). According to the 5th IPCC report, real evapotranspiration has tended to increase since the 1980s. Over the period 1982-2009, it would have increased globally by 1.51 mm / year (Zeng et al., 2014). In Nigeria(Hess,1998), Taiwan(Yu and al., 2002), and north America (Milly and Dunne, 2001), an increasing trend in reference evapotranspiration was observed, which was mostly linked to change in wind speed (case of Nigeria) and temperature (case of North America).

Dinpashoh et al.(2011) reported that in Iran, both statistically significant increasing and decreasing trends were observed in the annual and monthly ET_0 , depending mainly on wind speed change. The observation was reported by Zheng et al. (2009) in the Hai River Basin, for pan evaporation which found to be decreasing due to the declining wind speed.

Dayon (2015) confirm that in a hot climate, the reference evapotranspiration increases as a result of an increase in the energy available at the surface and in the specific humidity at saturation (warmer air can contain more water vapor) (IPCC, 2014).

By studying the sensitivity of evapotranspiration to climate variables change. Vicente-Seranno et al.(2014) showed that relative humidity, wind speed, and maximum temperature had stronger effects on ET_0 than sunshine duration and minimum temperature, whereas Goyal (2004) reported that ET_0 was most sensitive to temperature in India.

Whatever the climatic variable determining the trend of ET_0, its increase is already experienced in some regions and will continue to increase, implying a tendency to dry out especially with the decrease in projected precipitation. Hence, if the practices remain the same, the water requirements of agriculture will arrive earlier in the season and will be higher than current ones (Aubé, 2016). The increase in needs is greatest for fruit trees (Fader et al., 2016).

Conclusion

The main objective of this study was to evaluate the impact of climate change on the reference evapotranspiration ET_0 in Ifrane province. The results showed that the ET_0 will increase by 2050 in all months of the year and in a marked way for the RCP8.5 scenario. The increase of ET_0 will be more significant for May, June, July, August and September. The ET_0 maps clearly show differences between areas within the studied province; highlighting that north and north-west areas would be increasingly under water stress in the future. The estimated values are useful to predict corps water requirements in the study area, thereby providing a basic information for sustainable water resources management.

Climate change, which is now an indisputable reality, is having a strong impact on water resources. The consequences on the water cycle mainly concern the modification of the average and the geographical distribution of precipitation, the increase in evapotranspiration, the increase in periods of drought and heavy rainfall. In the hydrologic cycle, evapotranspiration represents around two-thirds of the volume of exchanges. Consequently, it is necessary to study this phenomenon deeply, as the direct measurements of this variable are limited, and therefore, little reliable information concerning the observed trends is available.

In the field of agricultural water management, we have to support research and consulting and to implement new approaches for a better sustainable cropping systems. There are short-term adjustments put in place during the campaign to combat occasional drought, and for which agricultural advice and forecasting tools play a key role. Long-term adaptations take place upstream of crop establishment, or even on the scale of several years, to design more resistant cultivation systems, and make extensive use of research (development of sustainable adaptation strategies of cropping systems (varieties, rotations, etc.) and territorial water management strategies). Finally, the development of the use of irrigation equipment that is more water efficient is an interesting lever.

Acknowledgments

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