Water availability changes for natural vegetation development in the mountainous area of Metsovo (N. Greece) for the period 1960-2000

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Abstract: Precipitation and evapotranspiration are driving parameters for the development of natural rain-fed vegetation. Purpose of this study is to investigate the annual, seasonal and monthly trends of reference evapotranspiration in conjunction with the effective rainfall in NW Greece and specifically in Metsovo, a mountainous area (alt. 1160m) located in Epirus. A time-series analysis of 40 years of monthly meteorological data from 1960 to 2000 was performed. Trends were identified under different confidence levels (a=0.05 and 0.1) by employing the Mann-Kendall test. The trends' magnitudes were estimated by the Sen's method. Results showed a significant increase of evapotranspiration in summer since 1960. The other seasons were almost unchanged or with slightly increasing trends, indicating thus more severe water stress conditions for the forest ecosystems in recent summers compared to the past. Further, the effective rainfall trends were positive on an annual basis. On a seasonal basis, however, results showed that the available water through precipitation has significantly increased only in winter and not significantly changed in summer, the season with maximum water requirements. Such changes indicate that Metsovo's local mountainous forest ecosystems will have to cope with and adjust to the climate changing conditions in the future.

1 Introduction

The climate change effect on the hydrological cycle parameters have increased research interest during the last decades (Milly and Dune 2001, Chen et al. 2007) mainly due to the high importance of water availability for natural vegetation but also due to the fact that changes in climate may induce changes in plant phenology (de Bie et al. 1998, Peňuelas et al. 2004). This is very important especially in the Mediterranean which is considered as both a biodiversity (Myers et al. 2000) and climate change hotspot (Giorgi 2006, Diffenbaugh and Giorgi 2012).

According to IPCC (IPCC, 2013), a global warming by 0.8°C is observed since 1960's and the air temperature increase is anticipated to increase further the next decades, with more intense changes during summer in the continental Mediterranean regions. Specifically in Greece, Tsiros et al. (2020) examined the changes of Thornthwaite's aridity index during three consecutive climatic periods from 1900 to 1997 and found that the index values have increased more rapidly during the latest climatic period (1960-1997). Proutsos et al. (2010) analyzed temperature data from 9 mountainous climatic stations (installed in altitudes from 510m to 1,310m) for the period 1960-2006 and found significant negative trends in annual mean and minimum temperature attributes and insignificant trends in maximum temperature in northern Greece. In the same work, however, significant positive temperature trends were detected in Southern Greece for maximum temperature with insignificant changes in mean and minimum values of air temperature. In lower altitudes, however, especially in S. Greece the temperature increase is more significant with higher changing rates (Proutsos et al. 2020).

Evapotranspiration and precipitation are the main water input and output attributes in rainfed forest ecosystems. Precipitation decrease (Todisco and Vergni 2008) in conjunction with neutral or positive evapotranspiration trends (Xu et al. 2005, Todisco and Vergni 2008) are already identified in many regions of the world, resulting to increased water stress for natural vegetation development. These general trends are, however, not followed in other regions (Wang et al. 2004, Chen et al. 2007).

This work is aimed at investigating the reference evapotranspiration and precipitation trends in the mountaneous area of Metsovo in Greece, during the period from 1960 to 2000. These attributes and their relationship play an important role in natural vegetation succession and conservation and also in drought tolerance. Therefore, any changes in these parameters can affect the species dynamics in plant communities, i.e. vegetation composition, spatial and temporal distribution especially in a high altitude Mediterranean region as Metsovo. To evaluate the impacts of changing water availability on natural vegetation it is of critical importance to continuously monitor climate conditions in order to implement, timely, adaptation and mitigation actions.

2 Data and Methodology

Data was obtained from the climatic station of the Institute of Mediterranean Forest Ecosystems installed in 1960 in Metsovo (Prefecture of Epirus, N. Greece) at 39° 47′ 07′′N, 21° 09′ 34′′E, alt. 1,310 m. The station was located in an opening of a black pine (*Pinus nigra*) forest with minimum impact from urbanization or land use changes that could affect the magnitude of the changing climate trends (Proedrou et al. 1997, Philandras et al. 1999).

Monthly values of air temperature and precipitation for the time period 1960-2000 were used in this study for the estimation of reference evapotranspiration (ET_o) and effective precipitation (ERain). They can be used as indices for the assessment of water availability of the natural vegetation since they generally express the main water inputs and outputs of a forest ecosystem. The temporal trends of these indices may then give a reliable assessment of the climate change effect on the forest ecosystems in the specific Mediterranean area located into a high altitude area and hosts species like *P. nigra* which are drought sensitive.
For the ET_o estimation, the Hargreaves and Samani (1985) equation was employed:

$$ET_o = 0.0023 \cdot \sqrt{T_{max} - T_{min}} \cdot (T_{mean} + 17.8) \cdot R_a \qquad \text{[mm]} \qquad (1)$$

where, T_{max}, T_{min} and T_{mean}, the maximum, minimum and mean values of air temperature, respectively, in °C and R_a the shortwave extraterrestrial radiation in mm. Ra is calculated by the formula of Duffie and Beckman (1991) in MJ m^{-2} d^{-1} (Eq. 2):

$$R_a = (24 \cdot 60 / \pi) \cdot G_{sc} \cdot d_r \cdot (\omega_s \cdot \sin\varphi \cdot \sin\delta + \cos\varphi \cdot \cos\delta \cdot \sin\omega_s) \qquad [\text{MJ m}^{-2}\ \text{d}^{-1}] \qquad (2)$$

where, G_{sc} = 0.0820 the solar constant in MJ m^{-2} min^{-1}, $d_r = 1 + 0.033 \times \cos[(2\pi/365)\times J]$ the relative Earth-Sun distance in rad, φ the latitude in rad, $\omega_s = \arccos(-\tan\varphi \times \tan\delta)$ the solar time in midday in rad, $\delta = 0.409 \times \sin[(2\pi/365)\times J - 1.39]$, the solar declination in rad and J the day of the year.
Monthly ERain was calculated from monthly precipitation (Rain) by the USDA method (Eq. 3):

$$ERain = \begin{cases} (Rain/125)\cdot(125 - 0.2\cdot Rain) & \text{για } Rain \le 250\ mm \\ 125 + 0.1\cdot Rain & \text{για } Rain > 250\ mm \end{cases} \qquad \text{[mm]} \qquad (3)$$

ET_o and ERain data were analyzed on a monthly, seasonal and annual basis, considering December of the previous year to February as winter months, March to May as spring, June to August as summer and September to November as autumn. Months with missing data more than three days were excluded from the analysis. The climate trends were detected by employing the Mann-Kendall non-parametric test (Mann 1945, Kendall 1975) for different confidence levels (α=0.05 and 0.1). Mann-Kendall method is widely used for climatic and environmental time series analysis and trends evaluation (Chen et al. 2007, Tigkas 2008, Karpouzos et al. 2010, Proutsos et al. 2010, 2011, 2020), since it is a reliable method to identify monotonic linear and non-linear trends in non-normal data sets (Helsel and Hirsch 1992). The slope of each trend was evaluated by the Sen method (Q Sen slope-Sen 1968), which can be used by accepting the existence of a linear trend in the analyzed data set (Gilbert 1987, Sirois 1998). The slope Q is then estimated as a median of all possible slopes. For the trends identification under different levels of confidence and the estimation of the Q slopes, the MAKESENS 1.0 software was applied (Salmi et al. 2002).

3 Results

In Metsovo, the average annual temperature is 9.8°C, ranging seasonally from 1.6°C in winter to 18.8°C in summer, with intermediate values (8.2 and 10.8°C respectively) in the transitional seasons of spring and autumn. The annual effective precipitation (ERain) is 886 mm, seasonally distributed almost evenly in winter (32%), autumn (29%) and spring (26%) but with low quantities in summer (13%). Annual ET_o is 808 mm with higher water requirements for vegetation in summer (46%) and lower (8%) in winter. The monthly pattern of ET_o and ERain is depicted in Fig. 1, indicating that the water deficit period of the year, for the region, begins in late April and ends in late September, resulting thus to a dry period with length of about five months.

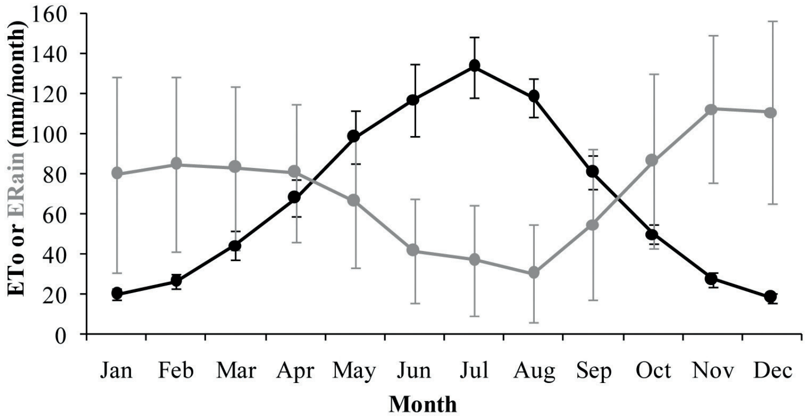

Fig. 1. Reference evapotranspiration (ETo) and effective precipitation (ERain) monthly average values along with their standard deviations in Metsovo, for the time period 1960-2000.

On an annual basis, ERain presents significant increasing trend (attributed mostly to the increased winter precipitation) with an average rate +6,01 mm y^{-1}, indicating that water availability conditions became more favorable for the development of natural vegetation in the region, since 1960 (Table 1). Increasing water demand due to evapotranspiration increase, however, is also observed during the summer period. The annual water demand, however, is only slightly increased compared to the past and is considered non significant.

The seasonal trends of the effective precipitation are also positive for all seasons. Statistically significant increasing trends, however, are identified only for winter, which present an average increasing rate of +4,38 mm y^{-1}. In all other seasons the increasing rates are smaller and not statistically significant (at least at a=0.1). The trends of reference evapotranspiration ET_o for the period 1960-2000 indicate minor and not significant changes in all seasons with the exception of summer when the vegetation water requirements are maximum. The average ET_o increasing rate during the summer season is +0,97 mm y^{-1} and is significant at a=0.1.

Table 1. Mann-Kendall test Z statistics and Sen's slope Q estimates of the monthly, seasonal and annual values of effective precipitation (ERain) and reference evapotranspiration (ET_o), for the period 1960-2000. Statistically significant values are highlighted in grey and the significance level is indicated with $^+$ for a=0.1 and * for a=0.05.

	ERain			ET_o		
	n	Test Z[1]	Q	n	Test Z[1]	Q
Monthly trends						
January	31	$+2.07^*$	+1.10	35	+0.17	+0.01
February	31	$+1.94^+$	+1.74	36	+0.42	+0.02
March	30	$+2.12^*$	+1.53	34	+0.18	+0.03
April	32	+1.64	+0.89	35	+0.65	+0.07
May	33	-0.23	-0.14	36	+1.43	+0.25
June	32	-0.08	-0.03	36	$+2.30^*$	+0.57
July	29	+0.43	+0.12	35	+1.62	+0.44
August	34	+1.39	+0.55	36	+1.27	+0.20
September	35	+0.11	+0.07	35	-0.43	-0.05
October	33	-0.36	-0.18	34	+1.19	+0.12
November	35	$+2.13^*$	+1.22	35	-1.62	-0.08
December	34	+0.77	+0.54	35	-1.65^+	-0.07
Seasonal trends						
Winter	26	$+2.20^*$	+4.38	32	-1.51	-0.12
Spring	29	+1.33	+1.58	33	+0.73	+0.21
Summer	25	+0.54	+0.45	32	$+1.70^+$	+0.97
Autumn	32	+1.02	+1.50	32	0.00	0.00
Annual trends						
Calendar year	18	$+1.67^+$	+6.01	28	+0.38	+0.65
Hydrological year	18	$+1.82^+$	+8.78	28	+0.30	+0.48

The combined analysis of ERain and ET_o in Metsovo since 1960 indicate that, in general, precipitation presents increasing trends whereas the evapotranspiration remains unchanged. However, summers become more dry due to the increased water requirements of plants induced to the increased ET_o and not to the decreased precipitation. Spring and autumn remain rather unchanged compared to the past (not significant changes). In spring, the slight increase in water availability due to increase of precipitation, however, is canceled from a slight increase of vegetation's water demands due to increase of evapotranspiration. On the other hand, in autumn the water availability conditions are more favorable for vegetation since the minor increase in precipitation is not accompanied by a similar increase in evapotranspiration. On a monthly basis, the ERain trends are generally positive and the rates are positive and higher in winter months becoming slightly positive or negative in summer months. The period from November to April presents increasing ERain values since 1960 with monthly average rates ranging from +0.54 mm y^{-1} in December to + 1.74 mm y^{-1} in February. The trends are significant for November, January and March (at a=0.05 confidence lever) and for February (a=0.1). Insignificant (a>0.1) are found the precipitation changes during the period from May to October. ET_o presents almost the opposite patterns compared to ERain, with trends to be positive and higher in the summer months and slightly positive or negative in winter months. The greater positive trend is recorded in June (increasing rate + 0.57 mm y^{-1}), while November and December present the highest though minor negative trends (decreasing rates -0.08 and -0.07 mm y^{-1}, respectively). From the monthly analysis, only the trends of June and December are identified as significant at confidence levels a=0.05 and 0.1, respectively.

4 Conclusions

In the present study two key factors of the water budget are assessed in terms of changing trends for the period 1960-2000 in the mountainous forest area of Metsovo. Recent precipitation changes appear to favor the development of natural vegetation compared to the past. The main limiting factor appears to be the changes of evapotranspiration resulting to higher water demand during the last years compared to the past, especially in summer. The effective rainfall presents positive annual trends which are significant in winter and remain almost unchanged in summer, when vegetation's water requirements are maximized. These changes can affect the local mountainous black pine forest, which will have to adjust to the changing climate conditions in the future if the recent trends persist. However, the climatic analysis presented in this paper should be further extended to assess other climatic parameters that affect trees growth and survival, such as temperature and/or drought related indices.

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