

PRECIPITATION VARIATIONS OVER THE LAST HALF OF THE CENTURY IN GREECE

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ABSTRACT

Precipitation is the main driving factor for vegetation development especially for the natural and agricultural rain-fed ecosystems. Its variation over years can affect the vegetation regime in a region. This study aims to evaluate precipitation changes over the last 50 years in Greece, occurred mostly in forested and agricultural regions.

Precipitation data from 32 meteorological stations with altitudinal (1-1.310 m) and latitudinal (37° 04' – 40° 29') expansion were analyzed for the time period 1951-2006 (for most of the stations). The trends in precipitation for each station along with their statistical significance were calculated on an annual, seasonal and monthly basis, using the Mann-Kendall test. The magnitudes of the trends were calculated using the Sen method of slopes.

The results of the study generally show significant decreasing trends in precipitation at most of the stations, with an average slope of -3.7 mm y^{-1} . Greater negative slopes and significant trends are identified in winter, but maximum absolute slopes are found in January, especially at low altitudes (less than 500 m). The trends during summer are negative but not statistically significant in most cases, because of the diminished rainfall at this time of the year in the Mediterranean region. On a latitudinal basis the trends are negative with greater absolute slopes in northern Greece, when at southern latitudes slightly positive and not significant trends are also found.

1 INTRODUCTION

Precipitation amount increased about 2% globally during the 20th century (IPCC 2001). Burns et al. (2007) reports an annual precipitation increase about 8% in Northeastern USA, with great regional variation (Keim et al. 2005) and also accompanied with temperature increases (Keim et al. 2003, Trombulak and Wolfson 2004, Burns et al. 2007).

The Mediterranean region is characterized by decreasing precipitation trends with natural seasonal fluctuations. The mean rates since 1900 in coastal regions show about 5% decreases. Though, greater negative trends are identified in 1960-1990 and become positive after 1990 (Palutikof et al. 1996, Piervitali 1997).

In south-eastern Mediterranean and Greece the decreasing trends remain up to 1990 (Hatzioannou et al. 1998, Kandyliis et al. 1989, Paz et al. 1998). Though, the changes in temperature vary widely, appearing to decrease in the mountainous high-elevation regions (Proutsos et al. 2010).

2 MATERIALS AND METHODS

Hydrological data from 32 meteorological stations were used in this study covering, for most of them, the time period 1950-2006. The sites geographical coordinations along with their elevations are presented in Figure 1.

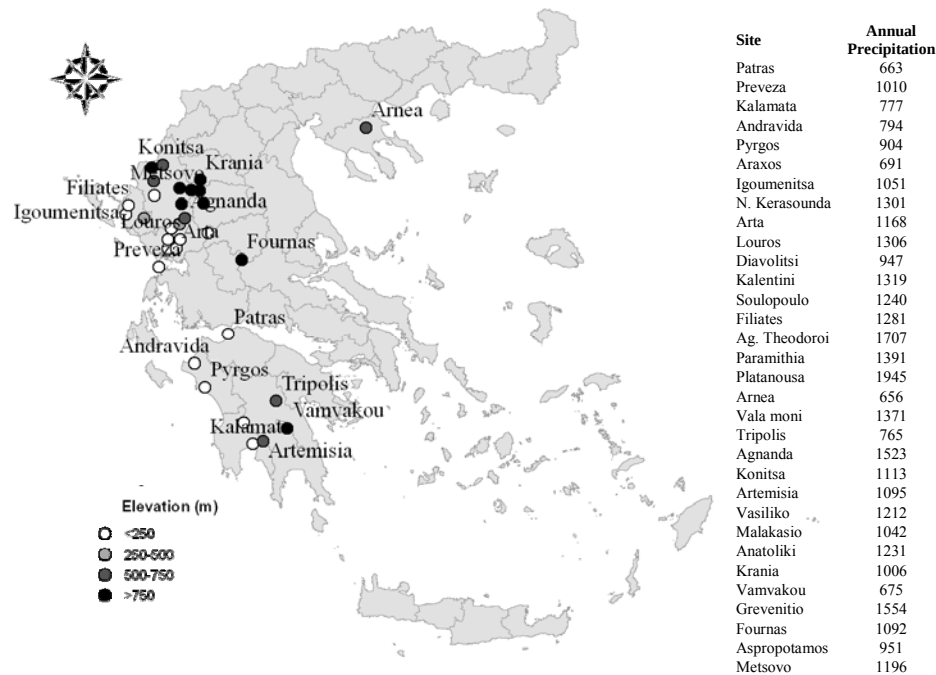


Figure 1. Geographical distribution of the meteorological stations used in the study. Data were derived from the Hellenic Meteorological Service, the Forest Research Institute of Athens and the Greek Electrical Company.

The raw data were provided by the Hellenic National Meteorological Service, the Forest Research Institute of Athens and the Greek Electrical Company. Monthly precipitation data from each station were summed in order to produce the seasonal and annual time series. Gaps in data were not filled in order to ensure the reliability of the results. The spatial distribution of the sites cannot be considered as uniform. Thus, the 32 meteorological stations were categorized in four classes according to their latitudes and longitudes (SW, SE, NW and NE) and in two classes according to their altitudinal distribution (the higher sites have elevations above 500 m and the lower, below 500 m).

The analysis was performed on monthly, seasonal as well as on annual basis and trends were examined under different levels of confidence. For the seasonal analysis, winter is considered as the period of the year from December (of the previous year) to February, spring from March to May, summer from June to August and autumn from September to November.

For detecting trends the Mann-Kendall non-parametric test (Mann 1945, Kendall 1975) was used as it is commonly preferable in hydrological and environmental research (Chen et al. 2007, Tigkas 2008, Karpouzios et al. 2010). A p-value less than

0.10 was used to indicate the trends statistical significance (Burns et al. 2007). The slope (Q) of each trend was identified by the method of Sen (1968), as a median of all possible pairwise slopes.

3 RESULTS AND DISCUSSION

On an annual basis, 75% of the stations (28 from the 32) have negative trends and at half of them (35% of their total number) are statistically significant at a confidence level $p < 0.10$ (Table I). In 8 sites the trends were positive, but only in 2 significant.

Table I. Monthly (J-D), seasonal and annual precipitation trends [(+: positive, -: negative and 0: unvaried (less than 0.1 mm y^{-1})] over the last 50 years for 32 meteorological stations, sorted by their altitude. The shadowed cells show the significant trends at a level of confidence $p < 0.10$.

Site	MONTH												SEASON				ANNUAL
	J	F	M	A	M	J	J	A	S	O	N	D	Winter	Spring	Summer	Autumn	
Patra	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-
Preveza	-	-	-	+	+	+	+	-	+	-	+	-	-	-	+	-	-
Kalamata	-	+	-	+	-	-	0	0	-	-	+	-	0	-	+	0	-
Andravida	-	-	-	0	-	0	0	0	-	-	+	-	-	-	-	-	-
Pyrgos	-	-	0	-	-	-	0	0	+	-	-	-	-	-	-	-	-
Araxos	-	-	-	-	0	0	0	0	0	-	+	-	-	0	0	+	-
Igoumenitsa	-	-	-	+	-	0	0	0	-	-	+	-	-	-	0	-	-
N. Kerasounda	-	-	0	+	0	0	0	+	0	+	+	+	-	+	0	+	+
Arta	-	-	-	-	+	+	+	+	-	+	+	-	-	-	+	+	-
Louros	-	+	+	0	0	+	0	0	-	-	+	-	-	+	+	-	+
Diavolitsi	-	+	+	0	-	-	0	0	+	-	-	+	+	+	-	-	-
Kalentini	-	+	+	+	-	-	0	+	-	-	+	+	0	+	-	+	+
Soulopoulo	-	-	+	+	0	-	0	+	-	-	+	+	-	+	-	-	-
Filiates	-	-	-	+	-	0	0	0	-	-	+	+	-	-	+	-	-
Ag. Theodoroi	-	-	-	+	-	-	+	+	-	-	+	-	-	-	+	+	-
Paramithia	-	-	0	+	-	-	+	+	-	-	+	+	-	+	0	+	+
Platanousa	-	-	-	+	-	-	+	+	-	-	+	-	-	-	+	-	-
Arnea	-	0	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-
Vala moni	-	-	-	+	-	-	0	+	-	-	-	-	-	-	-	-	-
Tripolis	-	-	0	-	-	0	0	+	0	-	-	-	-	-	+	-	-
Agnanda	-	-	0	+	-	-	+	+	-	-	+	-	-	-	-	-	-
Konitsa	-	-	-	-	+	-	0	+	+	+	+	-	-	-	+	+	-
Artemisia	+	+	+	+	0	-	0	0	0	-	+	+	+	+	0	+	+
Vasiliko	-	-	-	-	-	-	0	+	-	+	+	-	-	-	-	+	-
Malakasio	+	+	0	+	-	-	0	+	-	-	-	-	+	0	0	-	-
Anatoliki	-	-	-	-	-	+	+	+	+	-	-	+	-	-	+	-	-
Krania	-	+	0	+	+	-	-	0	-	-	+	+	+	+	+	+	+
Vamvakou	+	+	+	+	-	-	-	0	-	-	+	+	+	+	+	+	+
Grevenitio	-	-	-	+	-	-	+	+	0	-	+	-	-	-	+	-	-
Fournas	-	+	-	+	+	-	+	0	-	-	+	+	+	+	-	-	-
Aspropotamos	-	+	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-
Metsovo	+	+	+	+	-	-	+	+	0	-	+	+	+	+	+	+	+

In winter negative trends are recorded at the 72% of the stations though at the 32%, trends are statistically significant. In 9 stations (29%) trends were positive but only at 3 of them significant. In spring and autumn negative trends are identified at most sites (63% and 54% of their total number, respectively), though only at 13% and 16% respectively, trends were significantly negative. In summer the 54% of the stations have positive trends, but at none of them significant. Only in 2 stations the trends were negative and significant.

Extracting an average slope for each of the SW, SE, NW and NE groups of stations and then calculating the average of those four values, on an annual, seasonal and monthly basis, a mean decreasing annual rate in precipitation of -3.7 mm y^{-1} for Greece was found. The decreasing trend remains all seasons (Figure 2) becoming greatest in winter and autumn (-1.3 and -1.1 mm y^{-1}) and less in spring and summer (-0.6 mm y^{-1} for both seasons). The monthly trends are negligible for most months (Figure 3), but have greater negative slopes in January (-1.3 mm y^{-1}), October (-0.9 mm y^{-1}), December and June (0.5 mm y^{-1}).

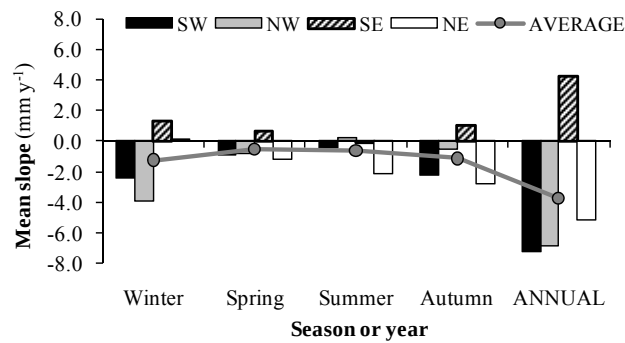


Figure 2. Seasonal and annual mean slope-values of precipitation changes in SW, NW, SE, and NE Greece. The average values are calculated as the mean of the 4 values per season.

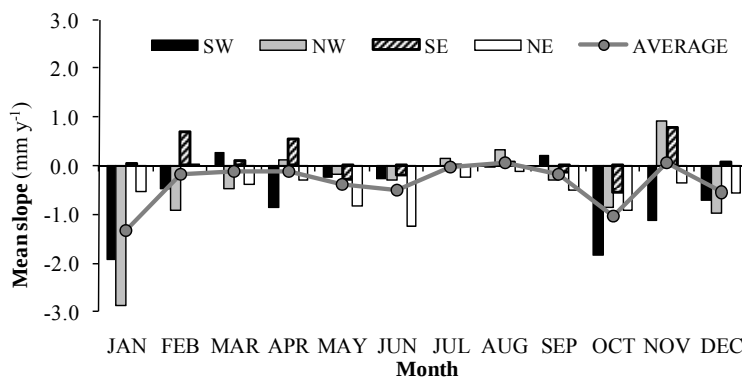


Figure 3. Monthly average slopes of precipitation changes for the different groups of meteorological stations classified according to their geographical positions. The average value for each month is calculated as a mean of the four values.

3.1 Southwestern trends

The southwestern (SW) precipitation time-series presents a decreasing mean annual trend with a slope of -7.2 mm y^{-1} . All 4 sites have negative annual trends and at 3 of them are statistically significant at a confidence level $p < 0.10$. The average slopes remain negative in all seasons, with greater precipitation decreases in winter and autumn (-2.4 and -2.2 mm y^{-1} , respectively) and lower in summer (-0.5 mm y^{-1}).

Greater variations are found at the monthly average slopes. The trends are generally negative almost for all months of the year, except in March and September, becoming slightly positive -almost negligible- ($+0.3$ and $+0.2 \text{ mm y}^{-1}$ respectively), indicating unvaried or slightly increasing precipitation for the region the last 50 years.

The greater precipitation decreases were calculated in January and October (-1.9 and -1.8 mm y^{-1} respectively).

3.2 Northwestern trends

The 23 northwestern (NW) stations show on average a decreasing precipitation trend the last 50 years, with a mean slope of -6.9 mm y^{-1} on an annual basis. The annual time series, for most sites (17), are negative and at 7 of them statistically significant at a confidence level $p < 0.10$. In only 6 sites, the trends were positive, but at none of them significant. The rates vary from slightly positive in summer ($+0.2 \text{ mm y}^{-1}$) to greater negative in Winter (-3.9 mm y^{-1}), indicating almost unvaried precipitation conditions in summer and greater decrease in winter. In spring and autumn the trends are generally negative but with relatively small slope-values (-0.8 and -0.6 mm y^{-1} respectively).

On a monthly basis the greater decreasing trends are identified in January, which has a station average slope -2.9 mm y^{-1} . April, July and August time-series show positive precipitation trends with rather small average slopes (less than $+0.3 \text{ mm y}^{-1}$). The greatest positive trend is found in November (-0.9 mm y^{-1}).

3.3 Southeastern trends

In the 4 southeastern (SE) stations, precipitation seems to have increased the last 50 years. The average annual rate is $+4.2 \text{ mm y}^{-1}$. The annual trends are positive at three sites (statistically significant at two of them) and negative (but also significant) at one. The trends appear to be positive all seasons, except from summer, when precipitation stayed almost unvaried. The greatest increases concerns winter ($+1.3 \text{ mm y}^{-1}$), though in summer and autumn the average slopes are not negligible ($+1.1$ and $+0.7 \text{ mm y}^{-1}$ respectively).

Greater increasing precipitation rates identified in November, February and April, whereas in October detected the greater decreasing average slope (-0.5 mm y^{-1}).

3.4 Northeastern trends

Only one NE station has a 50 year series of monthly data and used in this work. The analysis shows a significant ($p < 0.10$) decreasing trend in annual precipitation with a slope of -5.2 mm y^{-1} . The negative trends remain in almost all seasons (except from winter). The averaged seasonal slopes vary from $+0.1 \text{ mm y}^{-1}$ in winter to -2.8 mm y^{-1} in autumn. The monthly variability shows negative trends for all months (except from February which have a zero slope) with the greatest slope in June (-1.2 mm y^{-1}) and October (-0.9 mm y^{-1}).

Decreasing trends, but not statistically significant for most seasons, were also

detected by Karpouzou et al. (2010) in Pieria (NE Greece) for the time period 1974-2007. They calculated annual slopes varying from +2.3 to -7 mm y^{-1} among seasons, but the trends were not significant.

3.5 Altitudinal variations

Altitude does not seem to have significant effect on the precipitation trends. The site-average trend is decreasing, having a mean slope of -5.5 mm y^{-1} . The average slope-values between the 15 higher (above 500 m) and 17 lower (below 500 m) altitudes, differ slightly (-4.7 and -6.1 mm y^{-1} respectively).

The annual trends are negative for most (13) lower sites and significant at 6 of them. No significant positive trends were found. Higher, the annual trends were negative at 11 sites and at 6 of them significant. Only two significant positive trends were detected, both in SE Greece.

Similar results were found from the seasonal analysis (Figure 4). Although trends were the same at higher and lower sites, their slopes greatest difference was found in winter. Then, at the lower stations, the mean precipitation decreasing rate was -3.8 mm y^{-1} , whereas at the higher was quite smaller -2.0 mm y^{-1} , indicating greater decreases in winter precipitation at low elevations. Though, the differences in all other seasons were almost negligible.

The monthly trends were almost the same regardless of the altitudinal positions of the sites. Though, the magnitudes of the changing rates were generally greater lower, especially for the year period from October to February.

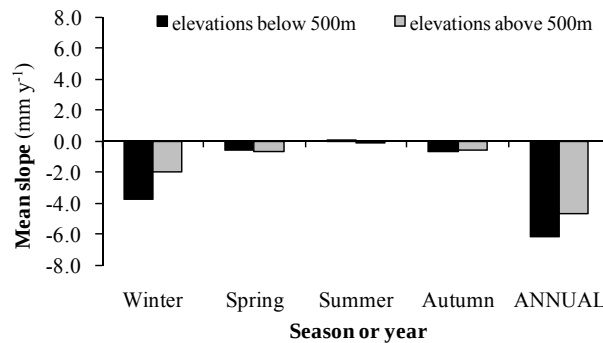


Figure 4. Seasonal and annual mean slope-slope values for precipitation changes in high (above 500 m) and low (below 500 m) elevations.

4 CONCLUSIONS

The annual precipitation in Greece appears to decrease the last 50 years, with a mean rate of -3.7 mm y^{-1} , but also with spatial variability. The greater changes are identified between western and eastern sites and they are slightly smaller between the northern and southern ones. In Southwestern, Northwestern and Northeastern sites, precipitation has decreased with mean rates -7.2 , -6.9 and -5.2 mm y^{-1} , respectively. Though, the Southeastern stations generally have positive trends with a mean slope of $+4.2 \text{ mm y}^{-1}$ indicating increasing precipitation the last half of the century, mostly

occurring in winter and autumn.

The changes in precipitation seems to be greater at the lower altitudes. At elevations greater than 500 m, annual precipitation decrease is slightly greater (-6.1 mm y^{-1}) compared to altitudinal lower sites (-4.7 mm y^{-1}).

Greater changes are detected in winter and autumn, especially in SW and NW Greece, but they are negligible in summer and spring because of the low rainfall during these seasons.

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