# Rainfall characteristics and drought conditions interconnected to the potentiality and applicability of the "DAPHNE" rain enhancement project in Thessaly

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## Abstract

The "DAPHNE" project aims at mitigating drought in Thessaly, by means of Weather Modification. An attempt is made to investigate several aspects of weather, climate and drought conditions in Thessaly, in order to determine the potentiality and applicability of a rain enhancement program over the area of interest. The area's geomorphological and geographical characteristics are investigated, identified and considered. Precipitation and temperature data from Larissa synoptic weather station are used to calculate, analyze and depict the Palmer Drought Severity Index (PDSI) for the last 60 years. Monthly precipitation amounts, together with potential evapotranspiration values, are also considered for a more detailed water balance. Although results indicate no significant changes on precipitation amounts, the increased agricultural activities, along with population growth and the not very well organized management of irrigation water, led to significant degradation of the area's water resources. Meteorological drought analyses revealed that, although near normal conditions -with negative values of PDSI- prevail during the last 60 years of the study, the examined area has suffered several drought spell periods in the past (1965-1971 and 1983-1999). On a monthly basis, PDSI values tend to decrease during the warm period of the year. Soil moisture deficit is observed from April until October, emphasizing thus the appropriateness of the potentiality and applicability for conducting a rain enhancement program in Thessaly area.

**Keywords:** Weather Modification, Rain Enhancement, Meteorological Drought, Thessaly.

## Introduction

The continued increase in water needs have considerably exhausted water resources, especially in semiarid areas, such as eastern plain Thessaly. Moreover, water needs increases considerably during the warm season of the year where minimum precipitation amount falls. Rain enhancement is a non-conventional and non-structural intervention for increasing the available water for domestic and agricultural use that can act as a tool for drought mitigation over semiarid areas of the world (Howell and Grant, 1973). For this reason the "DAPHNE" program aims at mitigating drought in Thessaly, by means of Weather Modification (Karacostas et. al, 2014). DAPHNE program is focused in the development of necessary scientific tools to support the potentiality and applicability of a well designed precipitation enhancement program over Thessaly.

Besides developing and applying state-of-the-art modeling tools, the project objectives are accomplished by performing measurement campaigns. During the experimental phase of the project, cloud seeding experiments take place on suitably chosen appropriate clouds over Thessaly area. Moreover, sampling of precipitated water and consequent soil is performed in order to investigate the impact of the seeding material on the environment. The synthesis of experimental data and the support of the modeling tools, leads on the establishment, within the project DAPHNE, of an innovative and integrated conceptual model, a useful tool for the mitigation of drought.

The objective on this study is to analyze some of the primary aspects of DAPHNE program related to rain characteristics and meteorological drought over the area of interest. In planning and designing a rain enhancement program, it is essential, as a first step, to carry out studies of rain characteristics as well as detection of severity, extent and periodicity of possible drought conditions. Cloud climatology studies and cloud microphysics analysis are also needed (Bojkov, 2007). These studies expect to clarify whether natural precipitation processes are efficient and if cloud seeding is likely to be effective.

Precipitation and its characteristics play an important role in determining not only the climate of a region but also almost every human activity. Therefore, knowledge of precipitation amount and its yearly and seasonal distribution are essential features for precipitation analysis. On the other hand, there is no universal definition of drought since; drought is defined according each particular problem that is referred. Therefore drought can be meteorological, agricultural, hydrological or even socio-economical. This paper investigates meteorological drought, defined as a meteorological anomaly characterized by prolonged and abnormal moisture deficiency (Palmer, 1965; Dalezios, 1989). To detect meteorological drought and access its severity the Palmer Drought Severity Index (PDSI) is used (Palmer 1965). Although PDSI is referred to as an index of meteorological drought, its computation involves not only precipitation but also potential evapotranspiration, and soil moisture conditions, which are determinants of hydrological drought and, indirectly, agricultural drought performing, thus, a more detailed water balance over the area.

## Data and Methodology

Daily measurements of air temperature and precipitation amount from Larissa weather station are used in this study in order to analyze precipitation characteristics and to compute PDSI and Potential Evapotranspiration. The period that the data covers extends from 1955 until 2010.

Precipitation analysis includes the computation of monthly and annual values of precipitation amounts and its yearly and monthly distribution. Time series of the annual total precipitation is constructed, for the whole period of study, and the linear trend is calculated. The mean monthly precipitation amount is also calculated.

Soil moisture deficit is derived from the difference of the Potential evapotranspiration (PET) value minus the average monthly precipitation and is calculated in mm. PET is calculated using the Thornthwaite’s method (Thornthwaite, 1948) that requires mean monthly temperature and monthly average daylight hours. The following formula is applied for the calculation:

$$PET = 16\frac{\mu N}{360}\left(\frac{10T}{I}\right)^{a} \qquad (1)$$

where: μ is the number of days in a month, N is the mean number of daylight hours in a particular month, T is the mean monthly temperature ($^oC$), I is an empirical annual index, the sum of 12 monthly index values I, calculated according to formula (2) and a is also an empirical exponent which is a function of I given by the formula (3).

$$I = \sum_{n=1}^{12}\left(\frac{T}{5}\right)^{1.514} \qquad (2)$$

$$\alpha = 0{,}000000675I^3 - 0{,}000077I^2 + 0{,}01792\,I + 0{,}49239 \qquad (3)$$

Drought estimation involves the computation of PDSI. The PDSI is calculated based on precipitation and temperature data, as well as the local available water content (AWC) of the soil. From its computation all the basic terms of the water balance are determined including evapotranspiration, soil recharge, runoff and moisture loss from the surface layer. Thus, PDSI can be considered not only as a meteorological drought index but becomes a hydrological index since it is based on moisture inflow (precipitation), outflow and water storage. PDSI does not take into account the long-term trend (Karl and Knight, 1985) and does not consider human impacts on water balance such as irrigation. It is computed on a monthly basis. Detailed description of PDSI can be found in Palmer (1965) research paper No 45. A more detailed description of PDSI computation for the area of interest can be found at Dalezios et. al., (2000).

## Results

The mean yearly precipitation amount for Larissa station is 431mm. The wettest year is 1955, having 772mm of precipitation, while the driest is 1970, with only 211mm. Appling linear regression on the yearly precipitation values a negative, not significant trend (at 5% level) is observed for the whole period of study, as seen in Figure 1. Any physical explanation of precipitation trend behavior would be highly inappropriate. It is worth mentioning that the wettest year recorded (1955), happens to be the first year of the data set, while the last two years (2009 and 2010) also appear to have increased precipitation amounts. Omitting either the first or the last two years alters precipitation trend, therefore, it is assumed that yearly precipitation amount has not altered during the period of study.

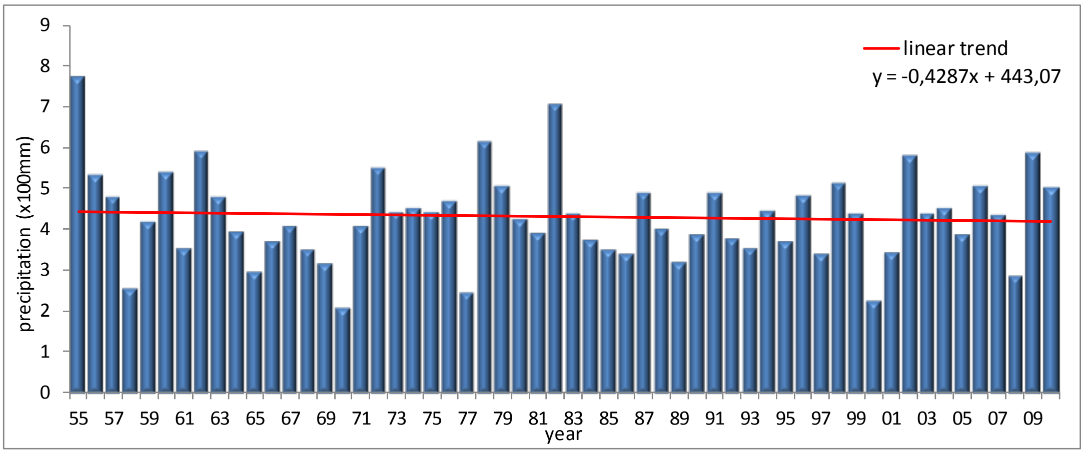


Figure 1: Yearly Precipitation amount and linear trend of Larissa weather station for the period 1955-2010.

The monthly average distribution of precipitation amount can be seen in Figure 2. Wettest months of the year, receiving over 50mm of rain per month, are the months October, November and December. The contribution (%) of that 3-month period to the annual precipitation amount is 37%. Minimum precipitation amount occurs during the summer months, with August being the driest month receiving only 15mm of rain, on average. The contribution of the summer months on the annual precipitation amount is only 13.6%. From the above analysis and the results on Figure 2 it is clear that the area receives maximum precipitation amounts at period far behind the period of increased water needs.

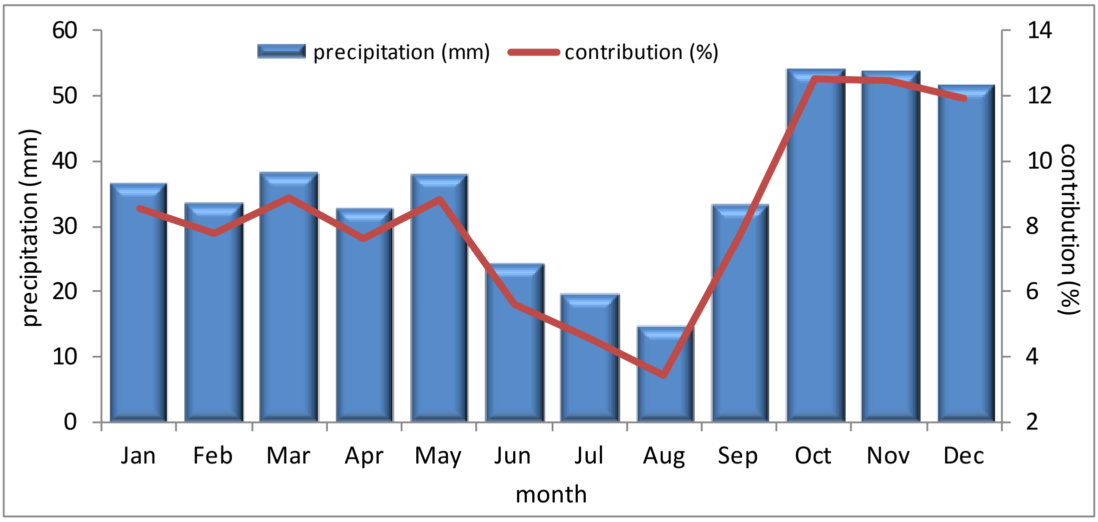

Figure 2: Monthly precipitation amount and contribution (%) to the annual precipitation of Larissa weather station for the period 1955-2010.

To detect the onset of meteorological droughts in central and northern Greece and assess their severity, an "objective" index is used, namely the Palmer Drought Severity Index (PDSI). The PDSI is one of the few general indices, which do address some of the elusive drought properties such as severity, onset time and end time. Although the PDSI is referred to as an index of meteorological drought, the procedure considers precipitation, evapotranspiration, and soil moisture conditions, which are determinants of hydrological drought and, indirectly, of agricultural drought. In addition, the PDSI is standardized for different regions and time periods, a necessary requirement for the areal assessment of droughts (Dalezios et al., 1991).

The yearly, averaged from monthly, PDSI values for Larissa station can be seen on Figure 3. Colors on Figure 3 denote the PDSI categories, as they appear in Table 1. From Figure 3 it is obvious that drought conditions (negative PDSI values) prevail, while isolated wet years appear sporadically receiving high PDSI values. Very wet conditions (+3<PDSI<+4) appeared only one year, 1963, moderately wet conditions (+2<PDSI<+3) appeared for four years (1956, 1979, 1982 and 2003) while slightly wet conditions (+1<PDSI<+2) appeared for three years (1978, 2009 and 2010). On the contrary, moderate drought conditions (-3<PDSI<-2) appeared for five years (1966, 1970, 1971, 1977 and 2001) and mild drought conditions (-2<PDSI<-1) appeared for 11 years. Finally, near normal conditions (-0,49<PDSI<+0,49) appeared for 24 years. In general, dry years with less severity drought conditions appear more frequent than wet years with higher severity wet conditions, characterizing the climate of the area.

Averaged monthly PDSI values, for the whole period of study, are calculated to evaluate the behavior of the index for each month. The results of this analysis appear on Figure 4a. All averaged monthly PDSI values receive negative values, between -0.27 on July and -0.05 on November indicating near normal conditions. On a yearly basis a decrease of the values is observed from April until July followed by a gradual increase until November. Apart from these observed seasonal variations of PDSI, the above analysis does not clarify the applicable period of a rain enhancement program.

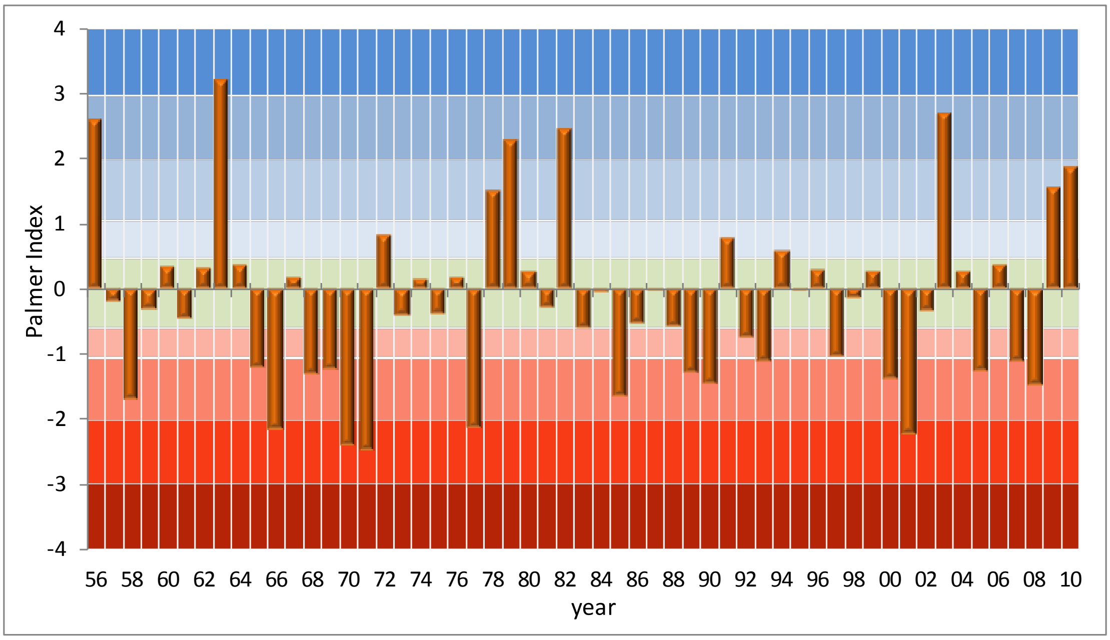

Figure 3: Yearly PDSI values for Larissa (1956-2010).

Table 1: The Palmer Drought Severity Index (PDSI) categories as developed by Palmer (1965).

| PDSI value | Moisture category |
|---|---|
| > 4.00 | Extremely wet |
| 3.00 to 3.99 | Very wet |
| 2.00 to 2.99 | Moderately wet |
| 1.00 to 1.99 | Slightly wet |
| 0.50 to 0.99 | Incipient wet spell |
| 0.49 to -0.49 | Near normal |
| -0.50 to -0.99 | Incipient drought |
| -1.00 to -1.99 | Mild drought |
| -2.00 to -2.99 | Moderate drought |
| -3.00 to -3.99 | Severe drought |
| < -4.00 | Extreme drought |

At this step, the difference between mean precipitation and Potential Evapotranspiration, according to Thornthwaite method, is calculated. The results of this difference, known as soil moisture deficit, are depicted on Figure 4b. As seen from Figure 4b soil moisture deficit appears from April until October, pointing the period that a rain enhancement program should be applied. Moreover, the onset of the program could be set 15 days before April, well in advance soil moisture deficit appearance. An extension for 15 days could also be applied at the end of the period until mid November.

## Conclusions

The study of precipitation characteristics and meteorological drought conditions in conjunction with the area's geomorphological and geographical characteristics suggested not only the need to conduct a rain enhancement program, but also the appropriate application method and period.

The first question on conducting a precipitation enhancement program over the area arises on what period this should be applied. A rain enhancement program could be applied either during the rainy season, to further increase the available water, or during the season where deficit appears if conditions are favorable. If the rainy season is chosen, additional water must be properly stored in artificial or natural water reservoirs for use during the period of increased needs. On the other hand, if the warm period is chosen, the program should be targeted exactly over the area on time water is needed (Bampzelis, 2013). The answer to the above argument lies within the area's geomorphological and climatological characteristics.

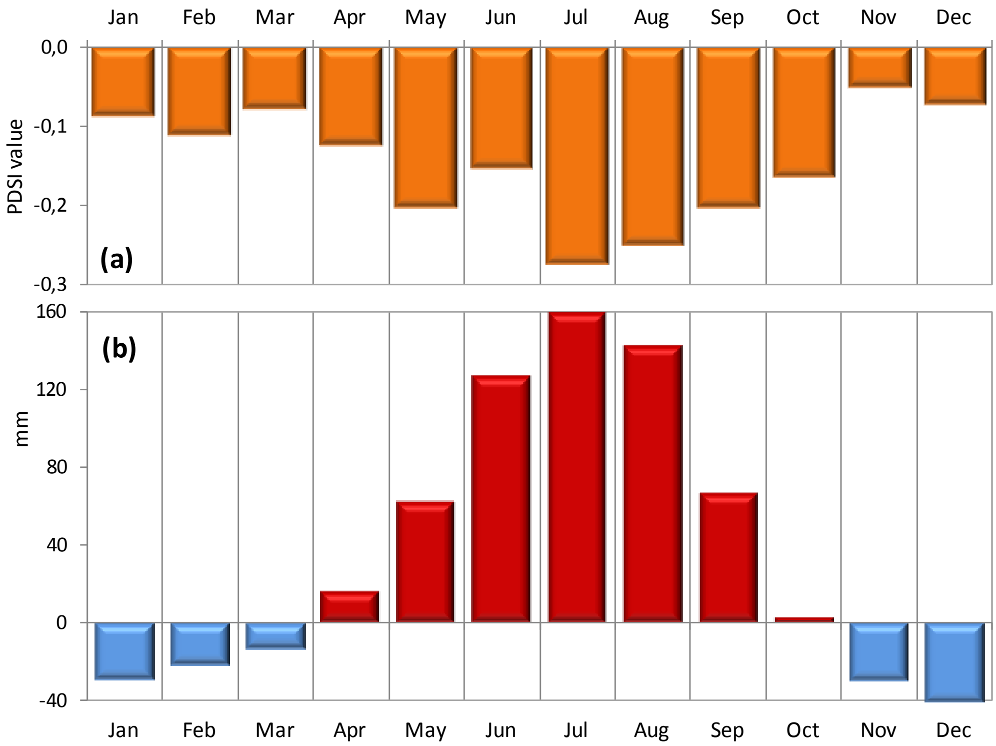


Figure 4: Monthly distribution of (a): average PDSI values, (b): soil moisture deficit for Larissa.

One of the key feature of the area is the gap between the period of maximum precipitation amounts (November - December) and the period of maximum water needs (July - August). The lack of adequate water reservoirs also deteriorates the situation. Therefore, the application of a rain enhancement program, aiming at augmenting precipitation during the cold season of the year, even successful, would have little or no impact during the period of increased water needs. Thus, application during the season of increased water needs targeted over the area, if successful, would have greater impact on drought relieving.
Rain amount analysis revealed that no significant change occurred during the last 55 years of this study. On the other hand, the area has suffered several drought periods during the same time.

In conclusion to the above, a rain enhancement program should be applied over the area during the period of increased water needs and when soil moisture deficit appears. This period, as analysis pointed, begins at beginning of April and ends by the end of September. According to that, the period from mid March until mid October is proposed as feasible period to conduct a rain enhancement program. This period is dominated by scattered convective activity and increased atmospheric instability. Focusing on that period the DAPHNE program, using state-of-the-science modeling tools, performing measurement campaigns and cloud seeding experiments investigates the potential impact of present weather and climate change on drought, in order to suggest effective ways of tackling the already existed -and for sure- future problem.

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