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SPATIAL – TEMPORAL ANALYSIS, VARIATION AND DISTRIBUTION OF PRECIPITATION IN THE WATER DISTRICT OF CENTRAL – EASTERN GREECE

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Abstract

In this study, the spatial and temporal distribution of precipitation in the Water District of Central – Eastern Greece is investigated for the 42-year period (1968 – 2009) by using monthly mean data from 35 rainfall gauges, with adequate spatial coverage. The basic objective is to infer the pattern of spatial variation of rainfall over the study area based on meteorological observations. The accurate estimation of rainfall's spatial distribution is needed whenever hydrological modelling is undertaken at the watershed scale for model calibration and validation. By using timeseries analysis and geostatistical methods, the regional and seasonal precipitation change and regime of this region during over 40 years is analyzed. However, this input is subject to uncertainty due to the random nature of rainfall. For all stations, uniformity checking and appropriate completion (where needed) took place and it appears that orography plays significant role as far the amount of rainfall is concerned. The results indicate that high variations in regional rainfall estimation occur in the mountainous areas, while the variance decreases in shadow areas in all seasons. The analysis of rainfall showed that there exists a wide variation in the rainfall amounts with variation from 382.4mm to 1397mm with a significantly decreasing trend.

Key words: *Regional – seasonal variation, timeseries analysis, trends, geostatistical methods, orography.*

Περίληψη

Στη μελέτη αυτή, η χωρική και χρονική κατανομή των βροχοπτώσεων στο υδατικό διαμέρισμα της Κεντρικής – Ανατολικής Ελλάδα διερευνάται για μια περίοδο 42 ετών (1968 – 2009) χρησιμοποιώντας μέσα μηνιαία δεδομένα από 35 βροχομετρικούς σταθμούς, με επαρκή γεωγραφική κάλυψη. Ο βασικός στόχος είναι να απεικονισθεί η χωρική μεταβολή των βροχοπτώσεων πάνω από την περιοχή μελέτης, με βάση μετεωρολογικές παρατηρήσεις. Η ακριβής εκτίμηση της χωρικής κατανομής της βροχής είναι απαραίτητη κάθε φορά, που υδρολογικά μοντέλα γίνονται σε κλίμακα λεκανών απορροής για την βαθμονόμηση και την επαλήθευσή τους. Με τη χρήση ανάλυσης χρονοσειρών και γεωστατιστικών μεθόδων, διερευνάται η εποχιακή μεταβολή των κατακρημνισμάτων κατά τη διάρκεια των 40 ετών. Ωστόσο, αυτή υπόκειται σε αβεβαιότητα λόγω της τυχαίας φύσης των βροχοπτώσεων. Για όλους τους σταθμούς έλαβε χώρα έλεγχος της ομοιομορφίας και κατάλληλη ολοκλήρωση (όπου απαιτήθηκε) και φάνηκε ότι η ορεογραφία παίζει σημαντικό ρόλο, σε ό,τι *αφορά το ύψος των βροχοπτώσεων. Τα αποτελέσματα δείχνουν ότι οι υψηλές διακυμάνσεις στην εκτίμηση της βροχής συμβαίνουν στις ορεινές περιοχές, ενώ η διακύμανση μειώνεται σταδιακά σε ομβροσκιερές περιοχές σε όλες τις εποχές. Η ανάλυση των βροχοπτώσεων έδειξε ότι υπάρχει μεγάλη διακύμανση στα ποσά της βροχόπτωσης κυμαινόμενα από 382.4mm έως 1397mm, με σημαντικά πτωτική τάση.*

Λέξεις κλειδιά: *Εποχική μεταβολή, ανάλυση χρονοσειράς, τάσεις, γεωστατιστικές μέθοδοι, ορεογραφία.*

1. Introduction

Climate change is one of the most critical issues for scientists from many areas, owing to its potentially serious global effects on both natural environment and human life. Today, climatic change has direct effects on increasing global temperature, altered precipitation patterns, melting glaciers and rising sea level (Hultstrand et al., 2008). The spatial and temporal distribution is crucial for advancing our ability to model and predict weather and climate changes. Its distribution is also important for water management, agriculture, electrical power, flood control, drought and flood monitoring on all spatial scales (Kusre, 2012).

Precipitation data are recorded by meteorological stations and rainfall gauges and the interpolation of climate data took place using several methods, such as graphical methods, including precipitation – elevation analysis and isohyets mapping (Subyani, 2004). Numerical methods including optimal interpolation such as kriging and its variants were developed in an attempt to spatially distribute rainfall. Analyzing the trend of climatic timeseries data is a methodology allowing the understanding of a potential trend in a given period of time. Identifying ascending or descending trends in climatic variables requires specific techniques, owing to the random values of climatic data. Predictions of average, maximum and minimum rainfall changes within the study area point to different patterns based on the location of regions. The aim of this study is to estimate the spatial distribution of long-term precipitation data obtained from 48 meteorological and rainfall stations and to identify trends on an annual, seasonal and monthly scale between 1968 and 2009.

2. Data Sources, Acquisition and Preparation. Research Methodology

The study is based on monthly precipitation data from 48 meteorological / rainfall stations situated across the Water District of Eastern – Central Greece where the investigated period is 1968-2009. The variability of seasonality for this climatic parameter is investigated as well as the irregularity of monthly precipitation distribution is analyzed providing a tool to determine the degree of climate's continentally character (Hatzianastassiou, 2008). Monthly rain gauge datasets are distributed irregularly throughout the Water District, but with a fairly good uniform density (Figure 1, left). The monthly mean precipitation timeseries are provided by the Hellenic National Meteorological Service (HNMS), the Ministry of Agricultural Development and Food (MADF) and the Ministry of Environment, Energy and Climate Change (MEECC). It is pointed out that several meteorological / rainfall stations beyond the Water District's limits have been taken into account in order to obtain a more representative picture of precipitation's spatial distribution (Figure 1, left).

In case there are missing data in the timeseries the following procedure is applied: first, the corresponding monthly mean substitutes the missing values; second, the correlation matrix is computed among the timeseries in order to select the surrounding timeseries with characteristics that most closely resemble those of the station with missing data; a linear spatial regression is then derived to interpolate the missing values so as to create reference timeseries for testing inhomogeneities. The statistical behaviour of the timeseries can be described on the basis of mean, maximum and minimum value, range, median, standard deviation, coefficients of skewness and kurtosis taken as measure of variability. Statistical analysis consists of a) sample concentration using histograms and empirical distribution functions, b) theoretical model adaptation (selection of a suitable distribution function, parameters' estimation and statistical control and adaptation), c) statistical forecast (variable estimation for a given return period or exceedance probability) and d) use of theoretical distributions for stochastic simulation procedures (Petalas, 2004).

The distribution of precipitation reveals strong gradients, with higher values corresponding to the West and North (over 1,100mm/yr) and lower values obtained towards the Southeast (below 400mm/yr). There are also inland regions with a relatively low precipitation regime.

3. Study Area's Location and Geomorphology

The Water District of Eastern – Central Greece administratively belongs to the Eastern Greece Prefecture, with longitude between $21^{0}49'$ - $24^{0}37'$ and latitude between $37^{0}55'$ - $39^{0}19'$

The Water District's total area is approximately 12.23×10^{3}km^{2}, where the mainland is bounded by the mountains of Orthris, Timphristos, Giona – Parnassos and Parnitha from the North, Northwest, Southwest and Southeast respectively. The rest of the area is surrounded by sea (Figure 1, left). The maximum elevation of the Water District is 2,431m, with the average elevation being at 417.5m, while the elevation 50% reaches 237m. The mountainous areas occupy a total of 9.2%, the semi-mountainous zone represents 14.9%, while the hills and valleys cover 38.8% και 37.1% respectively mostly concerning the coastal areas. In conclusion, the area's topographic relief can be considered flat to hilly. Analyzing the elevations of the study area's relief it is concluded that 20.2% of the total area concerns the altitude of 0-100m, 42.0% the altitude of 100-400m, 19.0% the altitude of 400-700m, 9.6% the altitude of 700-1000m and 9.2% the altitude over 900m (Figure 1, right). Finally, the prevailing geomorphological slopes are of the order of 0-10^{0} with percentage of 57.6% followed by those with values of 10-20^{0} (27.7%), 20-30^{0} (12.1%) and 30-45^{0} (2.5%), while slopes over 45^{0} participate only with percentage of 0.04%.

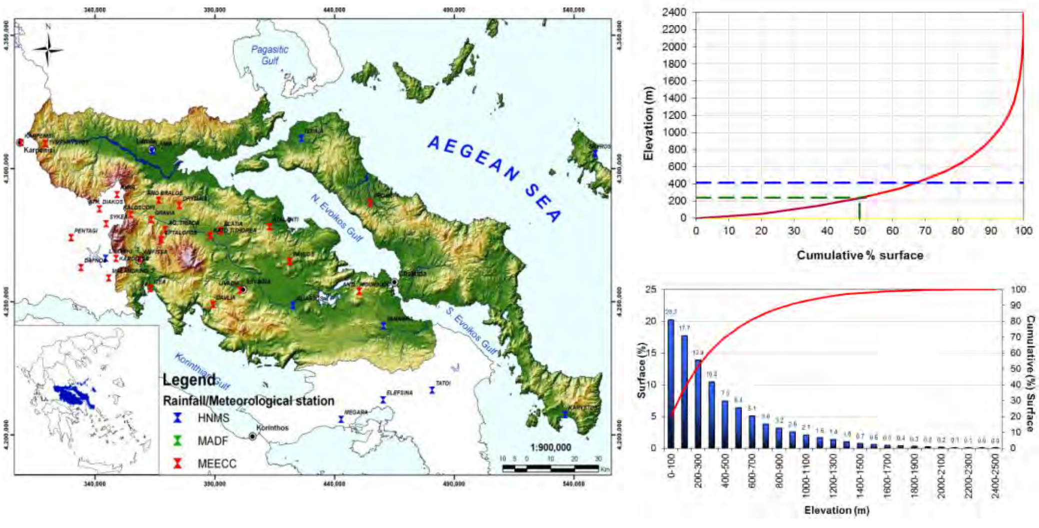

Figure 1 - (left) Geomorphological relief and rainfall / meteorological stations' geographical distribution of the Eastern – Central Greece Water District, (right) elevation vs. cumulative surface curve as well percentage of surface per 100m elevation.

4. Monthly, Seasonal and Annual Distribution of Precipitation Data

Processing of precipitation on a monthly basis was performed in order to determine those months with the greatest rainfall values contributing to the groundwater replenishment within the study area. The below histogram (Figure 2, left) shows that the most wet and humid month of the year is December followed by November and January. Instead, the months with the lowest rainfall are

July, August and June. Also, it can be shown that the major rainfall events start in October, reach their peak in December and remain at high levels until March. It has to be mentioned that some of the rainfall stations did not have continuous data for the 42-year period, so firstly the nearest stations (with almost similar geographical characteristics) with the strongest correlation were used in order to fill the missing data (double mass curve and regression functions with r>0.7).

In Pie chart (Figure 2, right) the seasonal rainfall distribution of all the stations is illustrated. As seen, winter accumulates precipitation at a rate of 40.4%, followed by 37.2% during fall, spring rate by 15.2%, while during summer season rainfall takes place only by 7.1%. Evaluating the two basic periods of a hydrological year (wet and dry) it seems that 77.6% of annual precipitation corresponds to wet period and only 22.3% to the dry one. Concerning the mean overannual rainfall (Figure 3), the highest values are recorded at Ath. Diakos, Dafnos, Pira and Pedayi gauges, while the lowest ones at Skyros, Mouriki, Itea, Megara and Elefsina stations. The arithmetic mean annual precipitation of the study area is 819.1mm, while the average rainfall values range between 1,397mm (Ath. Diakos station) and 382.4mm (Elefsina station). Based on the median value the rainfall stations with the highest and lowest values are the same as those mentioned above (Figure 4). Finally, as far as the highest and the lowest annually recorded rain values are concerned, Megara station represents the minimum annual rainfall (114.1mm in the year 1989), while Ath. Diakos rain gauge represents the maximum one (2,196.8mm in the year 1987).

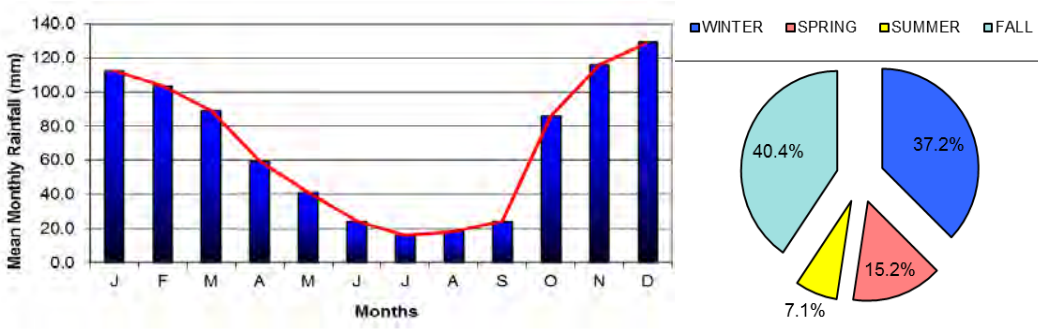

Figure 2 - (left) Histogram of monthly precipitation distribution, (right) pie of seasonal precipitation distribution within the Water District of Eastern – Central Greece.

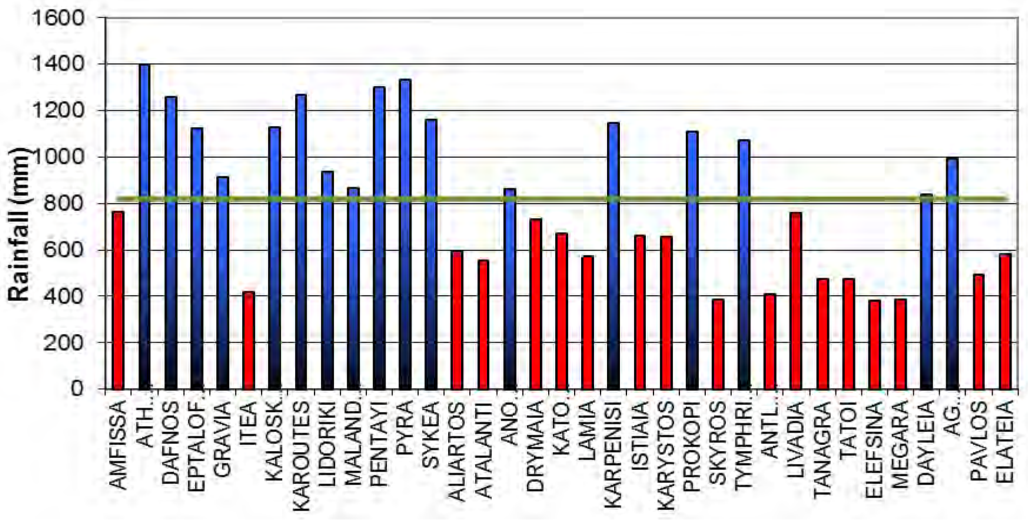

Figure 3 - Mean overannual precipitation of the stations within the study area. The thick green line corresponds to the arithmetic mean rainfall (819.1mm).

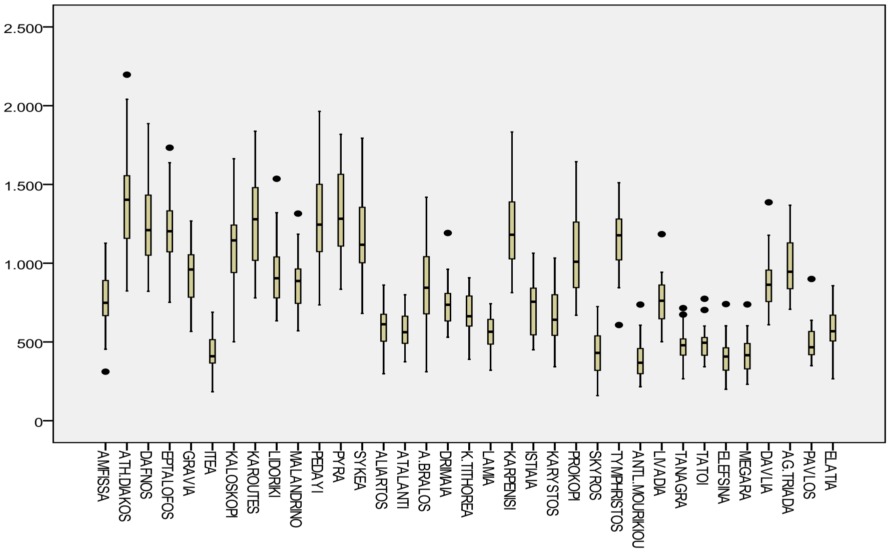

Figure 4 - Boxplot of the annual rainfall of the study area's stations. The linear extensions represent the highest and lowest observed values, the upper and lower limit of the box the percentiles of 75% and 25% respectively and the solid circles the outliers.

The key factor that affects the annual rainfall of a region is the land surface elevation. Thus, an estimation and identification effort of a mathematical relationship correlating rainfall with altitude is made within the study area. Evaluating the rainfall data from all the rain stations it seems that correlation coefficient between rainfall and stations' altitude is quite low (r^2=0.57) having applied the least squares method. Thus, it is obvious to determine two different regression functions: the one belonging to inland of Eastern – Central Greece and the other to Evia region with Sporades islands. The regression functions are expressed by the following equations:

Equation 1 - Regression functions between rainfall and elevation

P = 0.80Z + 452.6 (inland region)
P = 0.83Z + 444.4 (Evia and Sporades islands)

where P the rainfall and Z the elevation of each station. In both cases, the correlation coefficient is satisfactory ($r^2 \geq 0.70$), as it seems that besides the elevation there are other local factors (e.g. stations exposure on air masses, proximity to the sea, complex topographic relief with valleys and mountains etc.) that affect the precipitation values. From the first equation it is concluded that rainfall increases by 80mm every 100m of elevation, while the mean annual rainfall at sea level is 452.6mm (Figure 5, left). Similarly, in the second equation precipitation increases by 83mm every 100m of elevation, while the mean annual rainfall at sea level is 444.4mm (Figure 5, right).

It has to be mentioned that the second regression function (Evia and Sporades islands) is derived by very few rain stations (4) due to lack of reliable data from other rain gauges (no adequate data and very poor correlation, that is, $r^2<0.5$) thus, being under further discussion, analysis and research. Subsequently, the mean surface rainfall distribution is calculated with the geostatistical method Ordinary kriging (Figure 6, left). In addition, the variation between rainfall and stations' elevation is illustrated (Figure 6, right) using the above regression functions.

One of the most basic rainfall analyses is the statistical distribution in time so as to thoroughly examine the rainfall variation in an overannual scale and the various trends occurring in a given return period (Baltas, 2007). In Figure 7, the overannual precipitation variation and trend of the indicatively chosen meteorological / rainfall stations are depicted and as a result there is an obvious rainfall decline, making the groundwater replenishment even more difficult.

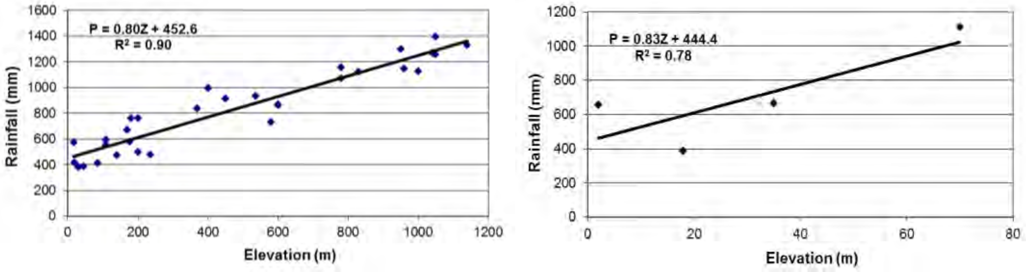

Figure 5 - Regression functions between rainfall and elevation for the inland region (left) and for Evia region and Sporades islands (right).

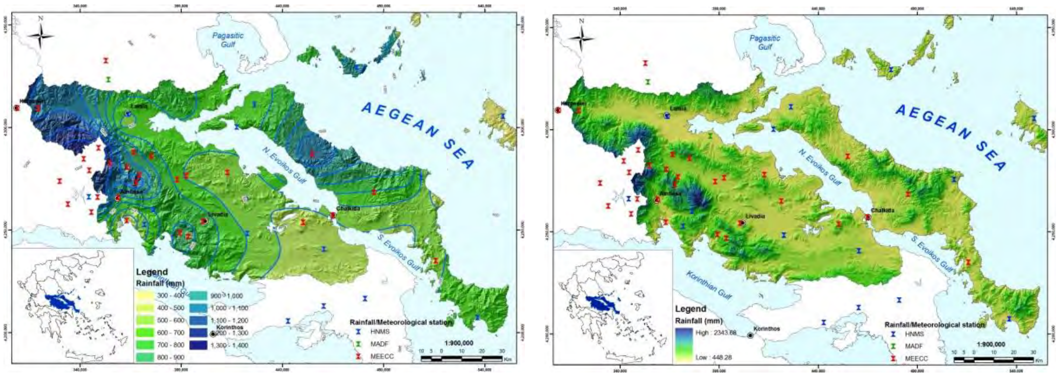

Figure 6 - (left) Surface rainfall distribution within the study area based on the geostatistical method Ordinary kriging, (right) precipitation – elevation variation using the regression functions.

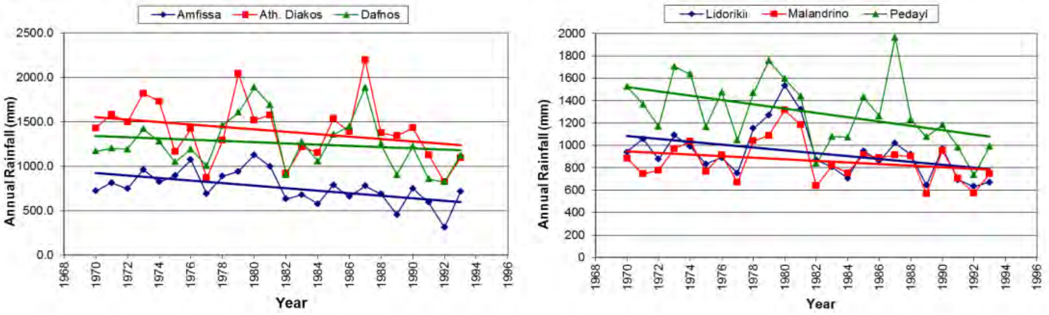

Figure 7 - Mean annual rainfall fluctuation for indicative meteorological stations in the Eastern – Central Greece Water District.

5. Probable Maximum Precipitation – PMP

Probable maximum precipitation represents the worst possible weather event and is the theoretical maximum rainfall of specific duration occurred but not exceeded in a given area, at a given location and time of year and under well – known meteorological conditions. One way of calculating PMP is the statistical method by Hershfield (Chen, 2007, Keramaris, 2008). This method is based upon the statistical characteristics (mean and standard deviation) of the annual maximum rainfall timeseries of a meteorological station. According to this method, the point PMP estimation h_m is directly derived by the mean value h and standard deviationη s_H of the annual maximum precipitation sample, namely by applying the following equation (Figure 8):

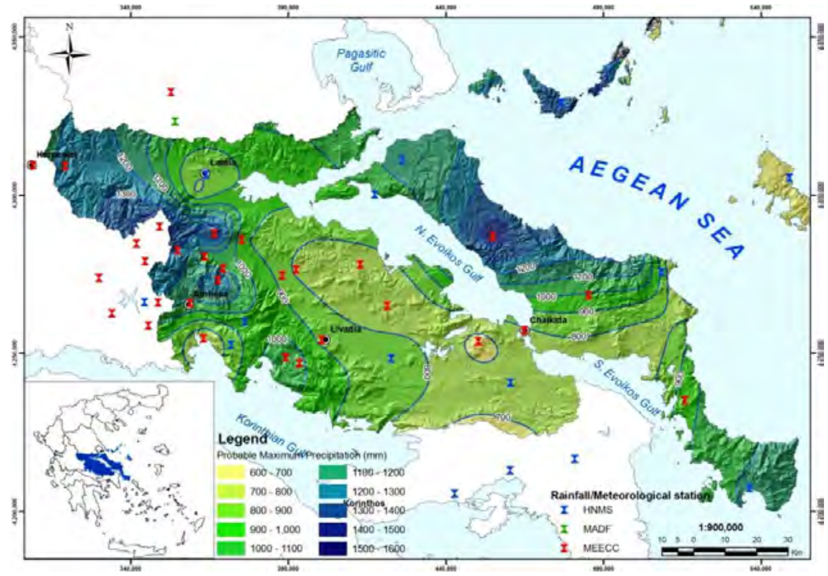

Figure 8 - Surface distribution of Probable Maximum Precipitation within the study area according to the geostatistical method Ordinary kriging.

Equation 2 - PMP calculation by Hershfield

$$h_m = \bar{h} + k_m \cdot s_H$$

where k_m is a dimensionless coefficient given by the following equation based on many rainfall samples statistical analysis:

Equation 3 - Calculation of the dimensionless coefficient k_m

$$k_m = 20 - \ln\left(\frac{\bar{h}}{130} + 1\right) \cdot \left(\frac{24}{d}\right)^{0.4} \quad (\bar{h} \text{ in mm, d in hours})$$

It has to be mentioned that PMP estimation, derived by the above equations, is refered to the point rainfall (Bostan, 2010, Fu, 2009).

6. Climatic Characteristics

Analyzing the study area's climatic characteristics, correlation between air temperature and rainfall takes place, so as the dry months to be determined according to Gaussen and De Martonne equations, while SPI (Standardized Precipitation Index) is determined based on rainfall data. Finally, the region is climatically classified according to Köppen and Thornthwaite classifications. Monthly Drought index by De Martonne is given by the following equation (Baltas, 2007, 2008):

Equation 4 - Monthly drought index by De Martonne

$I_{DM} = 12P_m / (T_m+10)$

where P_m is the monthly rainfall in mm and T_m the mean monthly air temperature in ^{0}C.

The value I_{DM} = 20 defines, according to De Martonne, a limit under which the ground soil has irrigation needs. The annual temperature range and the mean annual rainfall of each station are taken into account in order to apply the above equation. The monthly index I_{DM} is applied for each month based on mean monthly temperature and rainfall data for each gauge (the mean value of each month was calculated). Indicatively, only two rain stations are demonstrated in this paper due to lack of space, covering the one a mountainous area and the other a valley one to clearly show the meteorological and climatological spatial – temporal variation. From Figure 9, above (a, b), it seems that at Lamia station during the period from April to September – October the Drought index I_{DM} is lower than 20, which means that the ground soil needs to be irrigated. Accordingly, at Lidoriki station the ground soil needs irrigation from May to September. As far as the rest of the rain gauges is concerned, those covering the mountainous areas have similar characteristics with Lidoriki rain station and the ones located to semi-mountainous and valley areas behave like Lamia station, that is, irrigation period from April to September.

According to Gaussen, a month is considered dry when P<2T, where P and T are the mean monthly rainfall and temperature respectively. In order to examine the Gaussen criterion (Figure 9, below, c, d), the unit of the rainfall axis should be twice that of the air temperature one (2mm of rain correspond to 1^0C). As it seems at Lidoriki station the dry months are represented by June until September, while at Lamia one, the driest months are represented by May until September.

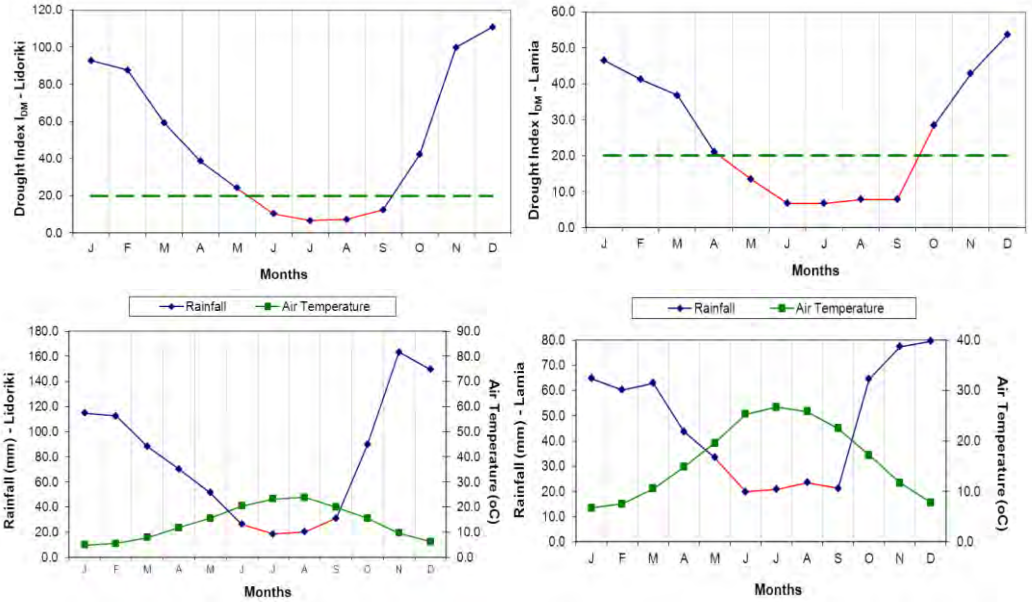

Figure 9 - (above) Monthly variation of Drought index I_{DM} according to De Martonne at Lidoriki and Lamia rain stations (a, b), (below) rainfall and air temperature correlation at Lidoriki and Lamia stations according to Gaussen criterion (c, d).

SPI is a drought indication quantifying the precipitation deficit for different time periods, thus reflecting its influence on the groundwater resources availability within a region. The mathematical relationship giving SPI is the following:

Equation 5 – Standard Precipitation index (SPI)

$$SPI = (X_i - \overline{X}) / \sigma$$

where Xi is the precipitation during the year i, $\overline{X}$ the mean rainfall for a specific time period and σ the standard deviation of rainfall during the specific time period. SPI takes both negative and positive values, from which the first ones correspond to drought events, while the second ones represent wet and humid events. From Figure 10, it seems that during the period 1988 – 1992 there is an extensive moderate to severe drought, unlike other years which occurs periodically a rotation between dry and wet periods.

Köppen climatic classification is based upon the statistical analysis of the climate impact on several factors such as temperature and rainfall regime. According to Köppen classification, the majority of weather stations belong to Csa climatic type. This type represents the Mediterranean climate characterized by mild, wet winters and mild, warm and dry summers due to the impact of subtropical anticyclones.

Thornthwaite climatic classification studies the relationship between vegetation and climate of each region and determines the temperature effect as well as the rain effectiveness. The rain effectiveness upon the vegetation is a function of rain and evaporation. According to this classification, the study area's climate is considered semi-arid to arid and dry, sometimes strongly influenced by the sea (Figure 11).

As mentioned before, only two (2) indicative rain stations, due to lack of space, were used covering both mountainous and lowland areas in order to determine the spatial and temporal difference and variation between the rain gauges within the Eastern – Central Greece Water District. The rest rain gauges follow, more or less, the same meteorological pattern depending on the elevation for each station.

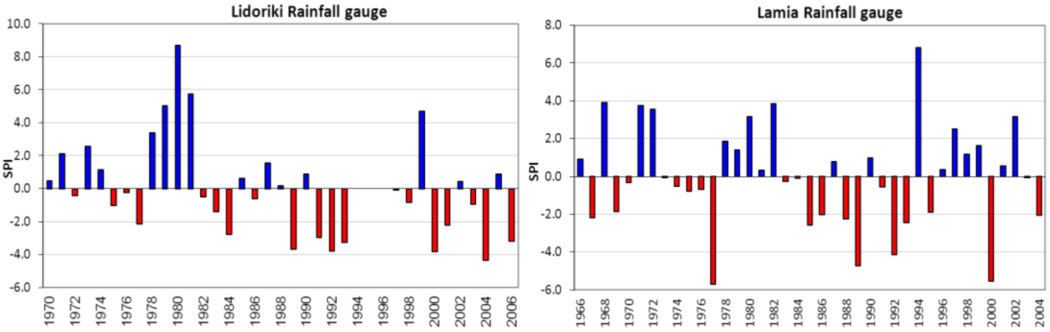

Figure 10 - Annual variation of SPI to indicative rainfall gauges at the Eastern – Central Greece Water District.

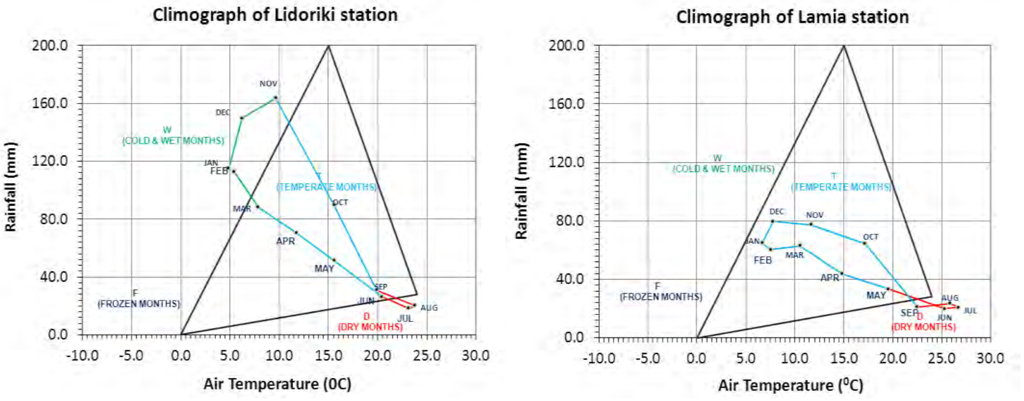

Figure 11 - Climograph of rainfall – temperature at Lidoriki (left) and Lamia stations (right).

7. Conclusions – Remarks

At the Water District of Eastern – Central Greece there is a satisfactory number of meteorological / rainfall stations which enables to deliver the most important statistical characteristics of monthly, seasonal and annual rainfall. The arithmetic mean annual precipitation is 819.1mm with a distinct rainfall differentiation between the mountainous and lowland gauges because of the intense topographic relief and rain's orographic role. Generally, a significant decline in precipitation may be observed throughout the stations' operation. Specifically:

- The time period from November to January is the rainiest, while the driest one is between June and August. During a hydrological cycle the months with the highest rainfall (wet period) thus replenishing the groundwater resources are October until March (>90mm for each month).
- The regression functions determined by the equations $P=0.80Z+452.6$ and $P=0.83Z+444.4$ for the inland region and Evia as well Sporades islands respectively, have significant correlation coefficient (over 70% in both cases). Where no sufficient data exist there should be made further discussion, analysis and thorough exploration and research.

8. Acknowledgements

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