Statistical analysis and Spatial correlation of rainfall in Greece for a 20-year time period

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Abstract Rainfall is a major natural process, with severe impact on human population. Recent changes in rainfall are directly linked with climate change. This study aims at the spatial and statistical analysis of rainfall in Greece during the last two decades of the 20th century. Its main objective is to investigate current conditions and evaluate emerging trends. Analysis relies on data from 74 meteorological stations all over the country and covers the years 1981-2000. Methodologically, the paper is divided into two parts. In the first part, Thiessen polygons have been created to determine their influence zones, and spatial correlation has been estimated using Moran's I index, weighted by appropriate spatial proximity matrices. Analysis has been performed using GeoDa software. At a second level, and having selected a representative sample from those stations, descriptive statistics were applied to determine current status and identify future trends. For each one of the years studied, analysis refers to two sub-periods, the dry and the wet one, as well as to the year as a whole. Differences detected between dry and wet seasons, as well as the similarities between wet and year period imply that the characteristics of annual rainfall are mainly conditioned by those of the wet season. This approach, if applied for multiple and continuous time-periods, could serve as a very useful tool for researching and analyzing future trends and spatial patterns, in different areas worldwide. Thus, important conclusions can come of about rainfall (or climatic in general) differentiations, possibly due to climate change.

1 Introduction

Climate change over the last decades is a very popular topic for research and study by many researchers worldwide. An important meteorological parameter related to climate change is rainfall. Natural disasters (desertification, floods, landslides, etc.) are directly linked to this natural phenomenon, along with socio-economic (compensation, water, irrigation, infrastructure, etc.), environmental (biodiversity, protected areas, pollution, etc.) and other aspects. In recent years, significant changes have been recorded in the rainfall regime worldwide, either with extreme rainfall or long periods of drought.

Several methods have been proposed to investigate and analyze this phenomenon, and there is important bibliography that supports them. Significant place among these occupy the methods of spatial and statistical analysis. One of these research efforts is the work of Goovaerts (1999), who attempts to integrate the altitude within spatial interpolation of rainfall with geostatistical approaches. A similar effort to associate rainfall - altitude, for Saudi Arabia, was made by Ahmadi

& Ahmadi (2013). In addition, surveys on the variability and distribution of rainfall, at different time scales and different climatic areas, were made by Nicholson (2000) for Africa and by Cannarozzo et al. (2006) for Sicily. Finally, a small-scale analysis of rainfall variability, in different climatic regimes, took place by Krajewski et al (2009). The above references are indicative examples of spatial and statistical rainfall analysis, through a large pool of corresponding research papers that have been published.

In this paper, we are attempting to analyze the spatial correlation of rainfall in Greece, as in this paper, we are attempting to analyze the spatial correlation of rainfall in Greece, as well as to investigate the current status and possible future trends through descriptive statistical analysis, based on rainfall data collected by meteorological stations covering the entire country. The study period is 20 years and covers the years 1981-2000. The aim is to draw conclusions and motifs on rainfall in Greece at the end of the 20th century, as well as the trends according to which the 21st century began.

2 Data and Methodology

The developed methodology is divided into two parts. First of all, the spatial correlation analysis of the data derived by the stations is attempted, and then, after selecting specific stations to cover the whole country sufficiently, a statistical analysis is made to investigate the status and trends of the rainfall. Rainfall data from 74 meteorological stations of HNMS (Figure 1) were used, for the period 1981-2000 (Skrimizeas, 2014). In detail, the total rainfall of each year for each station, as well as its division into wet (January to March and October to December) and dry season (April to September) were used. Finally, the results are presented with categorized maps and diagrams, but also with the tables of the calculated indices, in order to facilitate the interpretation and extraction of the desired conclusions.

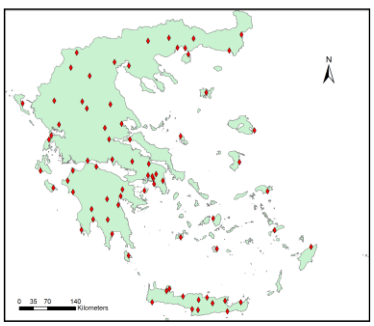

Fig. 1 Meteorological Stations

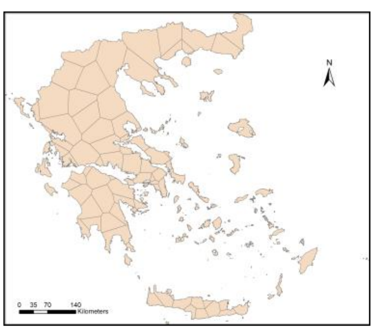

Fig. 2 Thiessen Polygons

For this reason, three different spatial and statistical analysis software platforms were used. In order to define the influence zones of the meteorological stations, the method of the Thiessen polygons (Figure 2) was used. A GIS software was used to create the polygons. The spatial correlation of the polygons was made using the Moran's I index, based on appropriate spatial matrices that were created. More specifically, the following matrices were created: Queen, Rook, k-Nearest Neighbors with k = 3, 4 and 5 (where k is the number of neighbors).

The index was calculated for each matrix and for all study periods (dry, wet, and total year for all 20 years) in order to assess the variation of the correlation index. At the same time, cluster analysis maps, as well as the corresponding maps of statistical significance, were produced for each case. All the above were processed through GeoDa software. For the statistical analysis of rainfall, 25 of the 74 stations were selected on the basis of sufficient coverage of the country. From the rainfall data of these stations the descriptive statistics for each year and for each of the three study periods were calculated. The Moran's I indices, calculated for each study period and each spatial matrix, as well as the scatter plots of the index with the highest value for each period, are shown in the following figures. The highest value of the index appears for the spatial matrix k4 (nearest neighbors) for all the three periods. All calculated indices are statistically significant (p-value = 0.001). Furthermore, the basic descriptive statistical indices for each study period were calculated and the average trend line for 20 years and for each period as well.

3 Results

The spatial correlation analysis demonstrated that, for all study periods and all spatial proximity matrices used, rainfall in Greece over this 20-year period under study shows strong positive spatial autocorrelation which is statistically significant, but differs between dry and wet period. The created clusters cover the areas of Greece in different ways, both in terms of spatial coverage and correlation type (high – high or low – low), depending on the period of analysis. It seems that the year period analysis follows the wet period pattern and is mainly conditioned by it. It is noted that due to the specificity of Greece (i.e consisting of many islands) the analysis using queen and rook matrices display areas without contiguities.

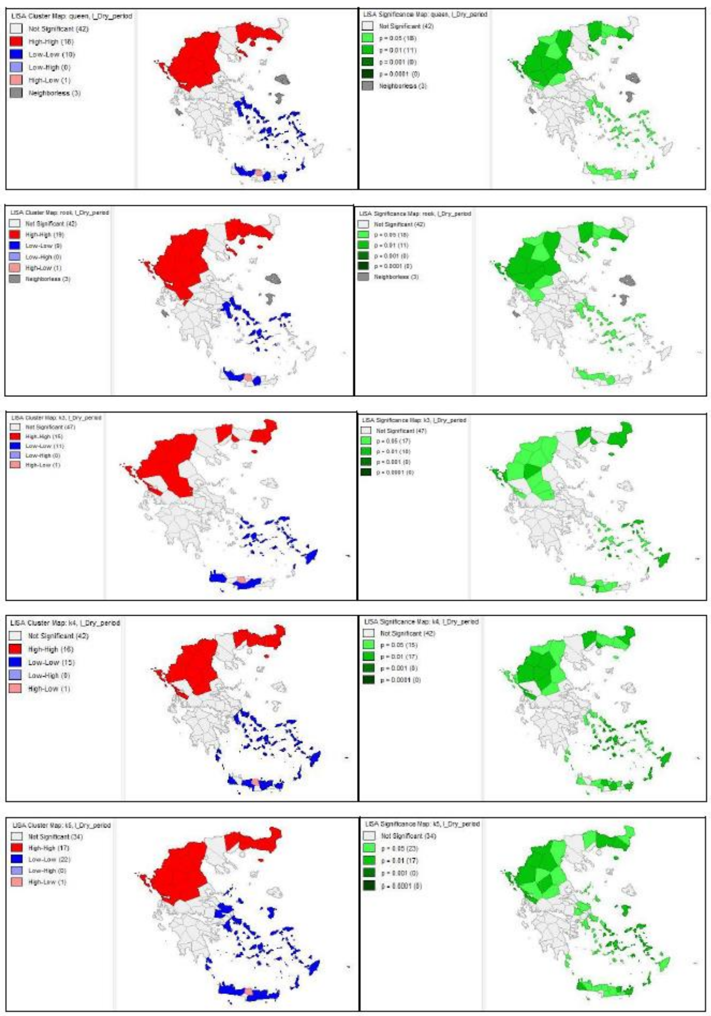

Fig. 3 Dry season clusters and statistical significance maps

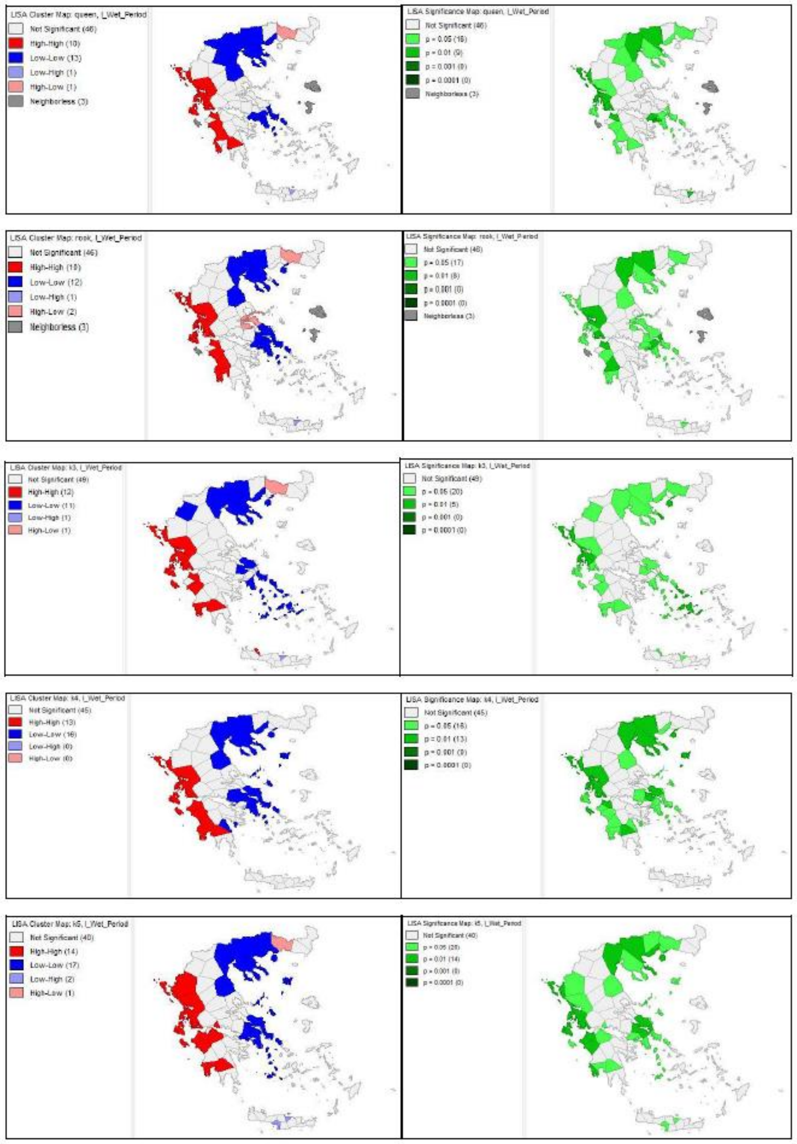

Fig. 4 Wet season clusters and statistical significance maps

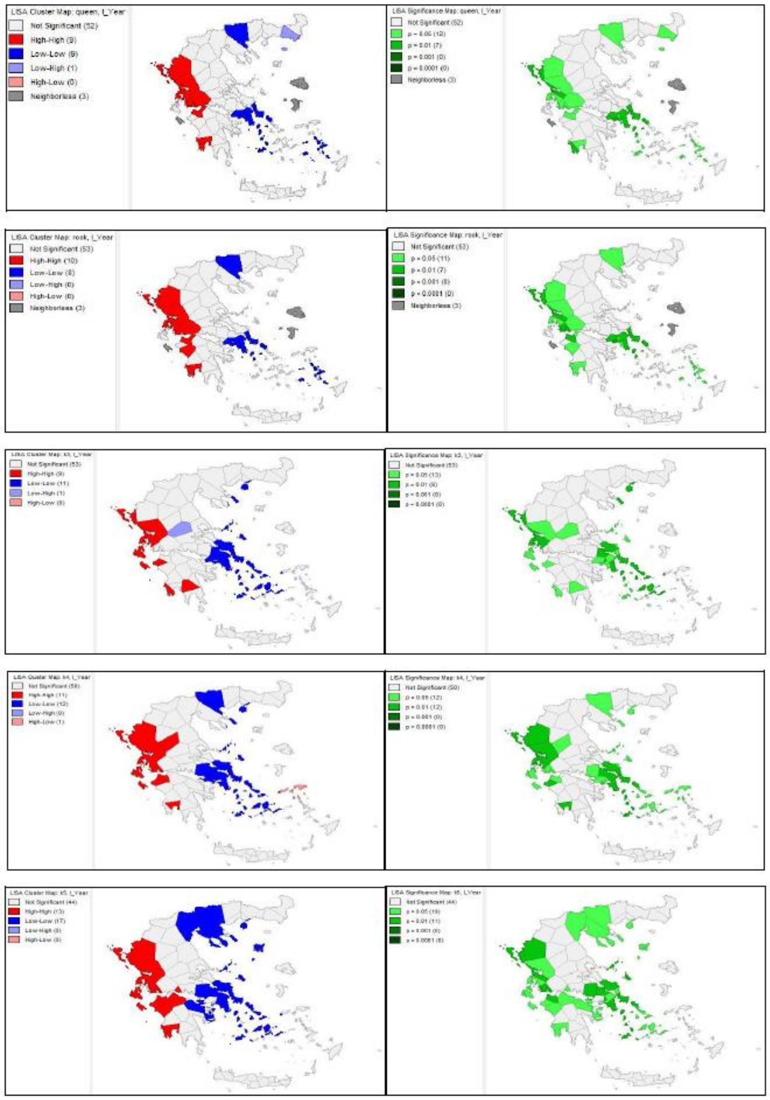

Fig. 5 Year clusters and statistical significance maps

4 Conclusions

According to the cluster analysis, for the dry period and for all matrices there appear two area groupings. There is an area of high positive values (high – high) in northeastern and northwestern Greece, as well as an area of low negative values (low – low) in the greater central, eastern and southern Aegean region (Fig. 3). As far as the wet period is concerned, these areas change into an area of low values (low – low) in northern and eastern mainland Greece and an area of high values (high – high) in western Greece (Fig. 4). With regard to the year period, the low value area (low – low) includes a part of eastern mainland Greece, a part of the islands of central-southern Aegean and a small part of northern continental Greece, whereas the high value area (high – high) covers a big part of western Greece (Fig. 5). The spatial clusters thus created are statistically significant.

The descriptive statistics of rainfall show a trend towards a decrease of the average value of rainfall, over the 20 years under study, being rather mild for the dry periods and stronger for the wet periods and year periods. The ranges and variations of rainfall values for the wet and year periods show a slight decrease in the middle of the period under study and a restoration trend, or even a slight increase, towards the end of the century with several outliers. The variability of rainfall values shows a downward trend in terms of the dry period with strong index variations over the 20-year period. On the contrary, the wet and year periods demonstrate a slight upward trend in the variability of values towards the end of the century, though with relatively mild variations of the index in the 20-year period. According to the equipartition measures, for the dry period, both the skewness of the values and the degree of kurtosis demonstrate a significant downward trend, showing a consistent trend towards the approximation of the normal mesokurtic distribution of rainfall values. The value fluctuation of the equipartition measures presents strong fluctuations during the 20-year period, though with a clear normalization trend towards the end of that period. A contrary pattern is observed for the wet and year periods, namely both the skewness of the values and the degree of kurtosis show a significant upward trend and, also the value fluctuation of the equipartition measures demonstrates slight fluctuations at the beginning of the 20-year period marked by a continuous increase of variations towards the end of that period. Consequently, spatial correlation of rainfall in Greece is positive and strong, though in different ways (clusters and interaction of values), depending on the study period (dry, wet, year period). The 21st century began with a slight downward trend of the average rainfall values for all periods, but with different statistical characteristics between dry, wet and year periods. It is worth noting that in all analyses, the year period is mainly conditioned by the wet period and largely follows its statistic and spatial patterns. Finally, it would be useful for the above conclusions to be updated (either to be refuted or reinforced) by repeating this analysis for the 20 years of the 21st century after their lapse.

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