TRENDS OF PRECIPITATION IN CYPRUS
RAINFALL ANALYSIS FOR AGRICULTURAL PLANNING

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1. Introduction

Crop production in semi-arid regions is largely determined by climatic and soil factors. The pattern and amount of rainfall are among the most important factors that affect agricultural systems. Rainfall is the limiting factor in these areas. It governs the crop yields and determines the choice of the crops that can be grown. Therefore, a detailed knowledge of rainfall regime is an important prerequisite for agricultural planning.

The analysis of rainfall for agricultural purposes must include information concerning the trends or changes of precipitation, the start end and length of the rainy season, the distribution of rainfall amounts through the year, and the risk of dry and wet spells.

The objective of this paper is a) to analyze recorded precipitation of one region of Cyprus for trends or changes and b) to demonstrate the direct method of analysis of rainfall data that can be used for agricultural planning.

For the first part of the study the statistical package SAS was used including EXCEL, while for the second part the statistical package INSTAT which was developed by the Department of Applied Statistics of Reading University, was mainly used. The analysis of trends of precipitation is part of the work undertaken by the Meteorological Service for the FAO Project concerning the reassessment of the island´s water resources and demand. The following paragraph gives an overview of the weather and precipitation conditions in Cyprus.

1.1 Overview of Cyprus Weather Conditions

Cyprus has an intense Mediterranean climate with a typical seasonal rhythm strongly marked with respect to temperature, precipitation and weather in general. Hot dry summers from mid-May to mid-September and rainy, rather changeable, winters from November to mid-March are separated by short autumn and spring seasons of rapid change in weather conditions.

The central Troodos massif, rising to 1951 meters and to a less extent, the long narrow Kyrenia mountain range, with peaks of about 1000 meters, play an important role in defining the weather conditions of Cyprus (Fig. 1). The predominantly clear skies and high sunshine amounts give large seasonal and daily differences between temperatures of the sea and the interior of the island. At latitude 35° North and longitude 33° East, Cyprus has a change in daylength from 9.8 hours in December to 14.5 hours in June.

In summer, the island is mainly under the influence of a shallow through of low pressure extending from the great continental depression centered over southwest Asia. It is a season of high temperatures with almost cloudless skies.

Precipitation is almost negligible but isolated thunderstorms sometimes occur which give precipitation amounting to less than 5% of the total in the average year.

In winter, Cyprus is near the track of fairly small depressions that cross the Mediterranean Sea from west to east between the continental anticyclone of Eurasia and the generally low-pressure belt of North Africa. These depressions give periods of disturbed weather usually lasting from one to three days and produce most of the annual precipitation. The average precipitation from December to February being about 60% of the annual total.

1.2 Overview of Precipitation Regime

The average precipitation for the year as a whole is about 500 mm but it was as low as 182 mm in 1972/73 and as high as 759 mm in 1968/69. The average precipitation refers to the island as a whole and covers the period 1961-1990. Statistical analysis of precipitation in Cyprus reveals a decrease of precipitation amounts in the last 30 years (Fig. 2a & 2b). Cumulative percentages of the total annual area average precipitation over Cyprus is shown in Fig. 2c.

The mean annual precipitation increases up the south windward slopes from 450 millimetres to nearly 1,100 millimetres at the top of the central massif. On the leeward slopes amounts decrease steadily northwards and eastwards to between 300 and 350 millimetres in the central plain and the flat eastern parts of the island (Fig. 2d).

The narrow ridge of the Kyrenia range, stretching 160 kilometres from west to east along the extreme north of the island, produces a relatively small increase of precipitation to nearly 550 millimetres along its ridge at about 1,000 metres.

Precipitation in the warmer months contributes little or nothing to water resources and agriculture. The small amounts that fall are rapidly absorbed by the very dry soil and soon evaporated by high temperatures and low humidity. Autumn and winter precipitation, on which agriculture and water supply generally depend, is somewhat variable. About 60% of the annual precipitation is recorded during the winter months (Fig. 3).

Snow occurs rarely in the lowlands and on the Kyrenia range but falls frequently every winter on ground above 1,000 metres. It usually appears in the first week of December and stops by the middle of April. Although snow cover is not continuous during the coldest months it may lie to considerable depths for several weeks especially on the northern slopes of high Troodos mountains.

A. TRENDS AND CHANGES OF PRECIPITATION IN CYPRUS

1. General context

There are many different ways in which changes in hydro-meteorological series can take place. A change can occur abruptly (step change) or gradually (trend) or may take more complex form. Climate change is often recognized as a progressive trend. Studies of precipitation change are typically complicated by factors such as missing values, seasonal and other short-term fluctuations (climate variability) and by lack of homogeneity of the data (e.g. due to changes in instrument and observation techniques).

There are many approaches that can be used to detect trends and other forms of non-stationarity in hydro-meteorological data. In deciding which approach to take, it is necessary to be aware of which test procedures are valid (i.e. the data meets the required test assumptions) and which procedures are most useful (likely to correctly find a change when it is present).

The present study is realized with the annual and monthly precipitation records covering the central Mesaoria plain area. The time series used have been chosen according to the Meteorological Service data quality check and in function of the length of the period of records. All time series used are continuous from 1917 to 2000, as the Meteorological Service has estimated the missing values.

The following paragraphs present the main results of the analysis of recorded precipitation in the Region D (Mesaoria plain) as shown in Fig.4, for trends and changes and the possible implication of the precipitation changes for the reassessment of the island´ s water resources. The first section includes the station´s selection criteria, the definition of the region and the regional precipitation indices. The second one is the main part of this study; it includes the analysis of trends of the precipitation records. The third section gives a picture of the consequences of the identified changes for water availability in the island which is followed by some recommendations.

2. <u>Data and Materials</u>

2.1 <u>Station´s Selection Criteria</u>

The period of study has been chosen as long as possible in function of the data availability. The Meteorological Service has realized a data quality check and estimation of monthly missing data for the selected stations. Before 1972, missing data have been estimated using data from the three nearest stations. After 1972 daily isoyetal maps were used. For the present study, monthly precipitation time series are available for the central Mesaoria plain for four stations Peristerona (st. no. 430), Kokkinotrimithia (st. no. 520), Kato Deftera (st. no. 580) and Lefkosia (st. no. 640) covering the period from 1917 to 2000. It is understood that the year used in this analysis is the standard hydrological year used in Cyprus (i.e. October – September).

A yearly double mass plot of the average precipitation of the region D, as defined in Fig. 4, in millimeters against the station´s yearly precipitation is realized to identify suspect time-series. In the same way the correlation coefficients between the stations and district yearly time series have also been used.

2.2 <u>Regional precipitation index</u>

For trends and regional temporal variations analysis it is useful to use a regional precipitation index as this eliminates part of the local variability associated with a specific station and not reflected by a regional change (Rossel et al., 1999; Rossel and Garbrecht, 2000). WMO (2000) is emphasizing the importance of using areally intergrated climate inputs as they provide more pertinent information on climate variability and less local “weather” type variability than station records of precipitation. The use of regional index gives a better regional significant to the analysis. The regional index used in this analysis is calculated as the average of this standardized precipitation of the stations included in the region. The regional index is calculated at the yearly and monthly time-scales. The use of standardized value is important to allow comparison of time-series when precipitation presents a significant spatial gradient throughout the area of study. This is the case in Cyprus with yearly average precipitation ranging from less than 300 mm in the central plain area to more than 1000 mm at the top of the Troodos mountains. The monthly and yearly precipitation time-series of the stations have been standardized with the long-term (1917-2000) mean and its standard deviation.

2.3 Homogeneity of the region (Mesaoria plain)

By homogeneity, we understand that the time-series follow similar temporal variations, with pseudo-proportional increase or decrease of the precipitation at all stations included in the region. If a region is homogenous, the analysis realized with the regional index will be also valid for all the stations included in the region.

The correlation coefficients between the annual precipitation of the stations and the regional precipitation time series have also been determined to quantify the homogeneity of the region. The correlation coefficients (r^2) for the referred region D range from 0.78 to 0.85 with an average of 0.8. Similar results were obtained from the other regions in Cyprus. A plot of the standardized yearly values of the stations and regional precipitation of region D, is shown in Fig. 5.

A plot of the seasonal distribution of the mean (Fig. 6) and coefficient of variation (Fig. 7) of the monthly precipitation of all the stations included in the region is realized to verify the similarity between the annual regimes of the precipitation at all stations. The differences between the coefficients of variation during the months of June, July, August and September are due to isolate precipitation storms during these dry months. The existence of rare precipitation event during the dry summer months leads to high standard deviation compare to the mean precipitation.

3. Identification of temporal changes in annual precipitation

The first step of the analysis includes the understanding of the precipitation evolution with the help of graphs and simple filtering of the annual precipitation (3.1). A series of statistical tests are then applied to the annual precipitation records to identify temporal changes, either in the form of a regular trend or in the form of a step change of precipitation data (3.2). The final paragraph compares this analysis with similar studies around the world (3.3).

3.1 Visual evidences of precipitation changes through the last century

Exploratory data analysis using graphs to explore and understand data is an essential component of any statistical analysis. The high inter-annual variability of the annual precipitation is shown in Figures 8 and 9. These figures also give a first idea on the type of precipitation change. It can already be seen that not many very wet years have been observed over the last 30 years, but the dry years of the same period are not drier than the dry years observed during the first 54 years. Similar comments can be concluded for the other regions in Cyprus.

The use of low frequency filters, five and eleven years moving average, highlights the decade scale variability of the precipitation. The five years scale variability is prominent with large variations (Fig. 10). The period of negative values starting in 1990 is the longest in the record. The graph indicates the possibility of a shift around 1970. As it can be seen in Fig. 10, the majority of the values are positives in the period 1917 to 1970 and negatives in the period 1970 to 2000. This shift is clearly apparent in most of the other regions as well.

The eleven years moving average filter out more of the inter-annual variability (Fig. 11). It suggests an overall decreasing trend even though there are periods of slight increase (1930-40, 1960-65 and 1975-80).

The mean, standard deviation and coefficient of variation of the annual precipitation were determined for the region over the 30 years WMO periods: 1921-50, 1931-60, 1941-70, 1951-80, 1961-90 and 1971-2000. For region D, the three parameters are relatively stable over the first five periods with values around 350 mm, 80 mm and 0,27 respectively (Fig. 12). During the last period, the mean is about 50 mm lower, while the standard deviation remains almost the same.

3.2 <u>Statistical evidence of precipitation changes through the last century</u>

Most of the statistical tests used here are well documented in the recent WMO publication "Detecting trend and other changes in hydrological data" (WMO, 2000). Additional information can be found in the following references: Sneyers (1975), Saporta (1990), Haan (1994), Hubert (1997).

3.2.1 <u>Preliminary statistical tests and consideration</u>

A significant trend is a trend that does not vary a lot if you add to or remove only few points from the time series. A non-significant trend will certainly disappear if you add one or two points that go against the trend. A significant trend is generally associated with an external factor affecting the process under consideration.

Three types of assumptions are commonly made when carrying out statistical tests: the form of the distribution (e.g. normally distributed), the constancy of the distribution (no changes in time) and the independence between the observations. The normal character of the distribution of the annual precipitation allows the use of parametric tests like the linear regression. Most of the tests used here are not based on the hypothesis of a normal distribution; they are non-parametric or distribution free tests. Because of the presence of a trend, the observations are not independent. For this reason, statistical tests based on the hypothesis of independence of the data should not be used.

3.2.2 <u>Linear trend in mean precipitation</u>

The objective of this section is to determine whether there is a significant linear trend in annual precipitation or not. All the regions, including region D, show a decreasing linear trend (Fig. 13). Table 1 shows that this trend is not significant at the 5% level according to the Mann-Kendall and Spearman tests for regions E and G. The linear regression r^2 of all the coastal regions (E to H) is not significant at the 5% level. In other words, a decrease in mean precipitation is observed everywhere throughout the island, but the decrease is statistically significant only for the Troodos Mountain regions and the dry central plain.

3.2.3 Step change in mean precipitation

The objective of this section is to check whether it is possible to divide the time-series in two stationary periods? All eight regions records include a shift or step change in mean which is significant at the 5% level (Table 2). The Hubert segmentation procedure suggests the segmentation of the time series between the hydrological years 1968-69 and 1969-70 for seven regions and between 1970-71 and 1971-72 for the central plain region D. All steps are significant at the 5% level according to the Sheffe´s test. The mean of the recent period is lower than the mean of the first period. The greater differences appear in the Troodos Mountains regions (A,B,C). The least differences appear in the western coastal region (H).

3.3 Is there a linear trend or a shift in the annual mean precipitation?

3.3.1 Statistical analysis

Both types of changes are statistically significant. However, it is obvious that a linear trend is imposed on a time series by the existence of a step change in the records. In its publication "Detecting trend and other changes in hydrological data", WMO is warning about the possibility of this kind of misuse of trend technique saying: "if there has been a marked step change in a data series then it is likely that a test for trend will give significant results, even though there is no trend" (WMO, 2000, page 51). To check if this is the case for the annual precipitation time series of Cyprus, the time series have been split in two periods according to the segmentation procedure results: 1917-72 and 1973-2000 for region D, and 1917-69 and 1970-2000 for all the other regions.

The trend and linear regression analysis carried out in all regions and both periods show that the decreasing trend is no longer significant, except for the older period in region C (Table 3, Fig.14). The linear regression line is almost horizontal over the older period for most of the regions. Over the recent period it still indicating a decrease but this is not significant, a single positive value in 2001 will modify completely the slope of the regression line.

3.3.2 Similar step changes around the world

Studies for changes in annual mean precipitation have been realized in several parts of the world. The essential results of a selection of them are presented here to place the results found with the Cyprus records in a general context.

A step decrease of the precipitation in 1970 has been identified in parts of Bulgaria and Romania (Carbonnel and Hubert, 1994). Several authors have analyzed hydro-meteorological time series in West Africa from Niger to Senegal (Carboneel and Hubert, 1985; Snijders, 1986; Hubert and Caarbonnel, 1987; et al. 1989; Paturel et al., 1997). They pointed out the nonstationarity of the series and suggest a climatic jump down between 1965 and 1972, the majority of the shifts appearing between 1969 and 1970. Precipitation in the Great Plains of the United States of America also show a significant change with an increase since the late 60´s, the last two decades being the wettest of the 20th century (Garbrecht and Rossel, 2000 and 2001). The Brazilian Amazon basin precipitation records show a shift near 1975, downward in the northern area and upward in the southern part (Marengo, 1999). The earth global air temperature was relatively stable from the 30´s to the 70´s; it is since then showing a strong increase.

All the above studies suggest the possibility of a world wide new climatic phase since the start of the 70´s. The origin of the climatic change can certainly be found in a general perturbation of the atmospheric and oceanic circulation at a planetary scale with different regional impacts. Even though climatic changes do not occur in one day, it is known that threshold effects and small variations in latitude of atmospheric systems such as jet-streams and low pressure convergence zones can result in relatively abrupt change in local mean precipitation. For a better understanding of weather and climate changes in Cyprus it would be interesting to look for existing studies or develop an analysis of the changes in tracks of depression systems in the eastern Mediterranean sector.

3.3.3 Discussion and conclusion

Most of the precipitation time series show a significant decreasing linear trend over the entire period of records. These results are in agreement with most of the previous studies realized with Cyprus precipitation records indicating a decrease in annual precipitation. However, we demonstrate that these trends are essentially due to a step change in mean precipitation around 1970. Several statistical tests indicate that the precipitation records include a significant shift or step change in the mean value of their time series. The segmentation procedure used and graphical analysis indicate that this shift occur between the hydrological years 1968-69 and 1972-73 that are respectively one of the wetter and dryer and years of the record in Cyprus. This period correspond to other climatic shifts observed in other part of the world. The results of the present analysis and those of previous studies demonstrate that the Cyprus precipitation records can be divided in two separate stationary periods.

4. Quantification of the precipitation step change

The previous paragraphs demonstrated that mean precipitation is lower during the last three decades of the 20th century. The main objective of this chapter is to realize a preliminary quantification of the precipitation changes. Both regional and station time series are used in this section to quantify the magnitude of the change and highlight the spatial variation of the changes. The recent and older annual and monthly mean precipitation are determined and compared. The 1971-2000 period is used as the recent period as it corresponds to the new standard 30-years used by the WMO. The older period corresponds to 1917-1970.

4.1 Changes in annual precipitation

The differences in millimetres between the annual mean precipitation of the recent and older periods have been calculated for the 8 regions and their associated 44 stations (Table 4). The differences are maximum in the Troodos Mountain area. They are larger than 100 mm at almost every station of elevation higher than 500 m.a.m.s.l. However, the differences are under 50 mm in the eastern and western coastal area (E and H). The lack of long records of precipitation in the southern slope of the Troodos Mountain, where some of the major dams are located, does not allow reliable deductions regarding mean precipitation changes for this area.

The differences between the annual mean precipitation of the recent and older periods in percent of the mean of the first period are given in Fig. 15 and Fig. 16. The larger differences appear in the Troodos Mountain area with maximum values in the northern slope (region C).

4.2 Changes in the distribution of annual precipitation

The objective of this section is to highlight the shift in the distribution of the annual precipitation. The precipitation time series were divided into three categories: Dry, Normal and Wet. To this end, the annual precipitation values of the entire period (1917-2000) were ranked. The lower third (0% to 33%) correspond to the Dry category, the central third (33% to 66%) to the Normal category and the higher third (66% to 100%) to the Wet years. In an evenly distributed time series, any 30-year sub-period includes approximately 10 Dry years, 10 Normal years and 10 Wet years. The annual time series of the annual precipitation in Cyprus are not evenly distributed. A shift appears around 1970. Table 5 shows the number of Dry, Normal and Wet years over the last thirty years (1971-2000). This table shows how rare Wet years are during the last 30 years compare to the number of Wet years of an evenly distributed time series. In four regions Wet years have been observed only 5 times, and only two and three times in the eastern part Troodos Mountain (regions B and C). The number of Wet years during the last 30 year is lower than in an evenly distributed time series, whereas the number of Normal and Dry years are larger. Paradoxically the number of Dry years is larger than the number of Normal years.

Figure 17 shows the cumulative distribution of the annual precipitation over the recent and the older periods. This chart confirms the results given in Table 5. Using Figure 17 as an example it can be seen that the difference between the two curves along their first quarters is only about 100 mm whilst the differences along their fourth quarter is about 200 mm. This indicates that the decrease is annual mean precipitation is essentially due to a reduction of the number of wet years and not to the presence of extremely dry years. The difference between the medians is roughly equal to the difference between the means (135 mm). Other information provided by this graph is the change in probability of non excess of annual precipitation between the two periods. For example, precipitation of 400 mm or less has been observed only in 80% of the years between 1917 and 1970 and in 90% of the years between 1971 and 2000. The median of the first period (350 mm) has been observed or exceeded in only 20% of the time during the last 30 years.

4.3 Changes in seasonal distribution of monthly precipitation

The objective of this section is to determine if the decrease in the precipitation appears throughout the year or if it is concentrated during specific months. Mean monthly precipitation has been determined for the twelve months of the year for both the 1917-1970 period and the 1971-2000 period for all regions and all stations. Figure 18 shows that the general shape of the seasonal distribution of the precipitation has not changed significantly. In both periods the mean monthly precipitation rapidly increase during the fall to a maximum in either December or January and a decrease more slowly through spring.

The differences between the monthly means of the two periods are represented in Figure 19 and 20. The greater decrease appears in the two wetter months (December and January) over all regions. The decrease is large in February in most of the island except the south-eastern part (regions E and F) where the decrease is very small. November and April are slightly wetter during the recent period than the older period in all the north-western regions (A, C, D G and H).

5. Conclusions and recommendations

The main objectives of this analysis were to analyze changes in recorded precipitation in Cyprus and the possible implication of the precipitation changes for the reassessment of the island´s water resources.

The statistical analysis of the records available over the period 1917-2000 demonstrates that the precipitation time series present a step change or shift around 1970 and can be divided in two separate periods. From 1917 to 1970 the precipitation records do not show any trend. From 1971 to 2000, the data show a slight decrease in the precipitation but this trend is not significant compared to the variations from year to year.

The shift in mean precipitation is larger in the Troodos Mountains sector than in other areas. The mean of the annual precipitation of the recent period is 100 mm or more lower than mean of the older period at almost every location of elevation higher than 500 m. This decrease ranges between 15% and 25% of the mean precipitation of the first period. The decrease of the annual precipitation is essentially due to a decrease of the precipitation during the months of December, January and February. Similar results were found in the other regions of the island.

The precipitation was significantly lower over the last 30 years than over the previous decades. Therefore, the available water in the island is probably lower than what had been assumed as a basis for water development works. For the reassessment of the island´s water resources, it is recommended to use hydro-meteorological records only over the 1971-2000 period corresponding to the new WMO standard. The use of this period for the quantification of the water resources will give a better picture of the water resources available today.

Secondary suggestions can be also made. For a better understanding of weather and climate changes in Cyprus it would be interesting to look for existing studies or develop an analysis of the changes in tracks of depression systems in the Mediterranean sector.

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