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RELATIONSHIPS BETWEEN HYDROLOGICAL PARAMETERS USING CORRELATION AND TREND ANALYSIS, CRETE ISLAND, GREECE

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The objective of this paper is to investigate the temporal relationship between the parameters of hydrologic balance in several basins on the island of Crete using correlation and trend analysis. Monthly rainfall totals, river discharge and estimated actual evapotranspiration (ET) from several representative basins in Crete were used. A moderate to strong association between the variations of rainfall and discharge was identified (r varied from 0.51 to 0.90). As a result, a greater than 66% rate of concurrent drought conditions for each river and its proximate rain gauge was found. In dry hydrological years river runoff decreased by 31% to 84%, compared to its mean annual rate. The change-point analysis detected increasing shifts in the second half of the 1980s in the mean of six out of nine annual time series of the ratio of precipitation to discharge. A second change, a diminishing in the rate, is estimated to have occurred around 1977/78. Only one site presented an increasing shift in the year-to-year variability, which occurred around 1984/85. A moderate association between the variations of rainfall and ET (r=0.63) resulted in greater than 50% of concurrent cases of meteorological and hydrological drought in three meteorological stations. At one out of three locations increases in the mean and standard deviation of the annual time series of the ratio of precipitation to ET were detected around 1998/99 and 1969/70 respectively, The time lag between the variations of rainfall with river flow variations ranged from 0 to 1. Zero to one month time lag was estimated from the cross-correlation analysis between rainfall totals and river discharge, while no time lag was observed between the former variable and ET.

INTRODUCTION

Due to interdependence of spatiotemporal distribution of water resources and the rainfall regime, the knowledge of hydrologic parameters is a useful tool for rational water resources management. Evaluating the components of water budget in a basin may contribute to the optimization of water resources management and overcome the disequilibrium in the water balance of the basin. The hydrology of groundwater is dependent on the hydrology of surface water. Stream flow in a river is derived from the hydrological balance of its watershed. Thus, for the estimation of the groundwater water potential, the estimation of the hydrologic budget is essential. The total recharge (Q_r) to an aquifer is given by the equation (Birkle et al., 1998):

$$Q_r = P_r - ET - R_{sur} + Q_{in} - Q_{out} \pm \Delta S \qquad (1)$$

where: P_r is the rainfall, ET is the actual evapotranspiration, R_{sur} is the surface runoff, Q_{in} and Q_{out} are the amounts of groundwater inflows and outflows, respectively, and ΔS is the change in groundwater storage. Considering the components Q_{in}, Q_{out}, and ΔS as negligible, the equation becomes:

$$Q_r = P_r - ET - R_{sur} \qquad (2)$$

To accomplish an equilibrium between natural recharge and abstractions from an aquifer, the components of the complete hydrological cycle, including rainfall, ET and surface runoff need to be known. Rainfall variability is one of the most challenging factors hydrological systems scientists and water resources managers face. The implications of any changes in rainfall or any other parameters of the hydrologic budget are likely to be greatest in aquifer systems, which can be highly stressed and include changes in groundwater level, in river discharge, in water quality, in water demands, and in soil moisture (da Cunha, 1989; Voudouris and Kallergis, 2002; Voudouris, 2006). For example, the Messara valley in the south of the island of Crete, which is the most important agricultural region of the island, is threatened by desertification due to falling groundwater levels by 20 m over the last 10 years of the 20th century (Croke et al., 2000).

A recent study focused on the spatial and temporal distribution of the rainfall in Crete found decreasing linear trends in annual rainfall totals, ranging from -0.3 to -9.7 mm/yr (Naum and Tsanis, 2003). However, in only two out of nineteen (19) stations was the slope relationship found to be significant. More specifically, a rainfall decrease was detected from the middle of the 1980s to the middle of the 1990s (Christodoulakis and Maheras, 2004). They found, however, some indications of increase at the end of 20th century. A seasonal shift of rainfall totals towards spring in southern Greece was also recently identified (Voudouris and Lambrakis, 1993). This shift resulted in an increase in actual ET, due to increased air temperature, and a diminishing of aquifer recharge.

The objective of this study is to investigate the temporal relationship between the parameters of hydrologic balance in several basins of Crete using correlation and trend analysis. Correlation based analyses have extensively been used in hydrological research (Neuman and de Marsily, 1976; Stefan et al., 2004; Bailly-Comte et al., 2006). Firstly, the temporal relationship of rainfall-river discharge and rainfall-actual evapotranspiration (ET) is explored, on a year-to-year and monthly basis. Then, a change-point analysis approach is applied to detect changes in the mean and variability of the annual time series of the ratios of precipitation to stream flow (precipitation/discharge) and ET (precipitation/ET). The aim of this study is to obtain a better understanding of the relationship between the hydroclimatic parameters and to an extent the impacts of the rainfall variations on river discharge and actual ET. The first section describes the water resources management of the study area.

WATER RESOURCES OF THE STUDY AREA

Crete is the largest island of Greece with a population of 600,000 habitants. More than two million tourists visited the island in 1999 (Chartzoulakis et al., 2001). The landscape of Crete follows the general pattern of Greek landscape consisting mainly of mountainous terrain. The mountainous carbonate masses of the Lefka Ori, Idi (Psiloritis) and Dikti mountains are the most important karstic hydrogeological systems in Crete (Figure 1).

The mean annual rainfall is 927 mm. It ranges from 300 to 700 mm in the lowland coastal areas and in the mountainous areas it can reach 2000 mm. A decrease of annual rainfall totals trending eastward on the island was identified (Voudouris et al., 2006). Despite the relatively high annual precipitation, it is estimated that about 63% is lost to evapotranspiration, 10% as runoff to the sea and only 27% goes to recharging the groundwater (Region of Crete, 2002).

The major water use in Crete is irrigation for agriculture (85.2 % of the total consumption) while domestic use is 12.7% and industrial use only 2.1% (Chartzoulakis et al., 2001). At present, only 72.7% of the total water demand is met, with the highest deficit for irrigation. The water demands of the island are predominantly met by groundwater extracted from a large number of boreholes. The most important limiting factor in Crete is regional and seasonal variation in water availability and demand. About 70-80% of annual rainfall occurs in 3-4 months, while summers are usually long and dry. Both agriculture and tourism require increased supplies in late spring, summer, and early autumn, when water is less abundant.

A recent study focused on the impact of rainfall variations in Crete aquifers showed that the quantity and quality of the aquifer systems depend closely on the hydrologic cycle (Voudouris et al., 2006). Prolonged dry periods cause groundwater level declines, deficient groundwater balance and water quality deterioration. The end of the dry periods marks the highest chloride concentrations measured in the coastal aquifers.

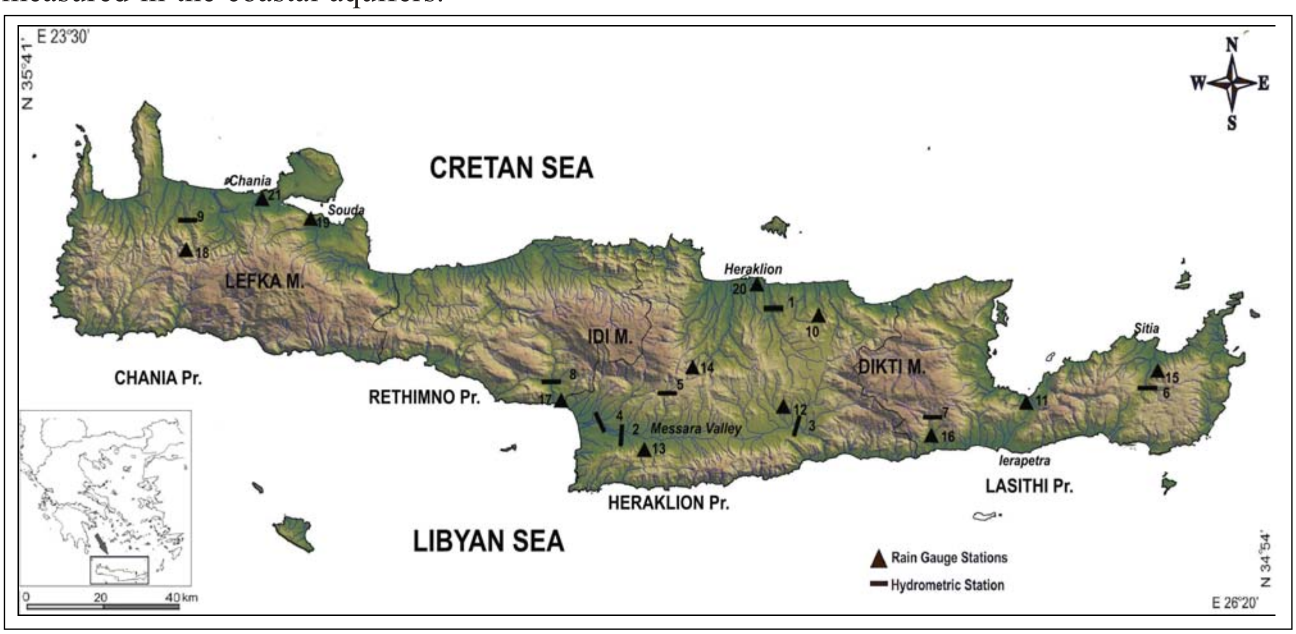

Figure 1. The locations of the hydrometric stations (▬) (1-9, Table 1) and the rainfall gauges (▲) (10-21, Table 2) in Crete, Greece.

HYDROLOGICAL DATA AND METHODS

The relationship between stream flow and rainfall variations was investigated employing monthly data of (a) river discharge recorded at nine (9) gauging stations (1-9) (Table 1 and Figure 1) and (b) precipitation totals measured at rainfall gauges (10-21) located in the proximity of the gauging stations on the river basins (Table 2 and Figure 1). The hydrological year in this study has been taken from the beginning of September to the end of August of the next year.

Mean values of ET and surface runoff (as percentages of precipitation) are also included in Table 1. These two components of the hydrologic budget together explained from 66% to 88% of rainfall totals. Unfortunately, monthly infiltration data were not available. In Crete, the highest mean monthly rainfall totals occur in winter (Table 2) due to weather instabilities from frequent changes from low to high pressure systems (Chartzoulakis et al., 2001). The majority of the highest mean river discharges were recorded in January and February (Table 1).

The rainfall gauges used were of the cylindrical weighting type, with a diameter of 10 cm^2. A small amount of oil was added to the gauges to prevent excessive evaporation losses. The stations mostly covered the more agricultural eastern part of Crete with fewer gauges in the west (Figure 1).

The coefficient of variation (CV) is often used to characterize the variability of hydrological variables and has the following form (Dettinger and Diaz, 2000):

$$\%CV = \frac{std}{m}100 \tag{3}$$

where *std*=standard deviation and *m*=mean value.

Table 1. Gauging stations with latitude, longitude, and area of basin. River discharge includes the mean, the coefficient of variation (CV) and the peak months (mean monthly maximum values). Hydrologic budget includes actual evapotranspiration (ET) and surface runoff (R_{sur}) (as percentages of precipitation) during 1977-97.

	Gauging Station*, Prefecture	River basin	Lat. Long	Area (km^2)	Mean (10^6 m^3)	CV (%)	Peak ($10^6 m^3$) [month]	ET (%)	R_{sur} (%)
1	Potamies, HER	Aposelemis	35º 16' 25º 13'	75	10.7	0.78	2.4 [Feb]	49.6	16.7
2	Faistos, HER	Geropotamos	35º 03' 24º 47'	398	15.5	1.10	3.9 [Feb]	71.5	10.3
3	Demati, HER	Anapodiaris	35º 02' 25º 17'	520	28.6	0.76	7.9 [Feb]	71.5	9.6
4	Faneromeni, HER	Koutsoulidis	35º 05' 24º 51'	97	11.5	0.63	3.3 [Jan]	54.4	8.4
5	Agioi Deka, HER	Lithaios	35º 04' 24º 57'	42	6.3	0.71	1.6 [Jan]	58.3	18.7
6	Maronia, LAS	Patelis	35º 08' 26º 05'	36	5.9	0.59	1.5 [Jan]	58.4	14.2
7	Mythoi, LAS	Myrtos	35º 02' 25º 35'	102	10.8	0.63	2.3 [Jan]	55.6	13.4
8	Agia Galini, RETH	Platys	35º 06' 24º 41'	205	49.1	0.57	13.9 [Jan]	46.2	22.2
9	Voukolies, CHA	Roumatianos	35º 27' 23º 47'	12	6.9	0.65	21.0 [Mar]	69.0	19.0

* Location as seen in Figure 1.
HER=Heraklion prefecture, CHA=Chania pr., LAS=Lasithi pr., RETH=Rethimno pr.

Table 2. Rainfall gauges with geographical information including latitude, longitude and altitude. The hydrological periods and statistical characteristics of precipitation totals, including the mean, the coefficient of variation (CV) and the peak months (mean monthly maximum values) are also given.

	Rainfall Station*, Prefecture	Alt (m)	Lat Long	Hydrol. Year	Mean (mm)	CV	Peak (mm) [month]
10	Avdou, HER	230	35º 14' 25º 26'	68/69-00/01	793	0.25	142 [Jan]
11	Pachia Ammos, LAS	50	35º 05' 25º 49'	68/69-02/03	567	0.32	120 [Dec]
12	Demati, HER	210	35º 02' 25º 17'	68/69-96/97	438	0.30	101 [Dec]
13	Pompia, HER	150	35º 01' 24º 52'	67/68-96/97	493	0.28	106 [Dec]
14	Gergeri, HER	450	35º 08' 24º 56'	67/68-02/03	852	0.28	197 [Dec]
15	Maronia, LAS	150	35º 08' 26º 05'	67/68-94/95	651	0.22	139 [Dec]
16	Mythoi, LAS	200	35º 02' 25º 35'	64/65-02/03	587	0.26	135 [Dec]
17	Agia Galini, RETH	20	35º 06' 24º 41'	69/70-02/03	597	0.30	134 [Dec]
18	Palaia Roumata, CHA	200	35º 24' 23º 47'	71/72-02/03	1267	0.23	247 [Dec]
19	Souda, CHA	146	35º 29' 24º 07'	59/60-04/05	638	0.31	128 [Jan]
20	Heraklio, HER	39	35º 33' 25º 18'	55/56-04/05	487	0.26	94 [Jan]
21	Chania, CHA	62	35º 50' 24º 03'	61/62-99/00	609	0.29	123 [Jan]

* Location as seen in Figure 1.
HER=Heraklion prefecture, CHA=Chania pr., LAS=Lasithi pr., RETH=Rethimno pr.

For river discharge, CV varied from 57% and 110% (Table 1), and for rainfall the range is between 22% and 32% (Table 2). The smaller variation of CV for rainfall compared with that of discharge is due to the influence of orography on stream flow response to rainfall and evapotranspiration. Stefan at al. (2004) attributed the locally observed differences between the CV of the same two hydrological variables in southern Romania to the fact that the stream flow response to rainfall is shorter and more intense than the time intervals during which evaporation can influence the river flow. As a result, drought yields less discharge than might be expected from the corresponding annual rainfall variation.

The temporal relationship between monthly actual ET and rainfall variations was investigated employing data from the last three stations (19-21) in Table 2. The actual evapotranspiration in this study was computed on the basis of the procedure described by Thornthwaite and Mather (1955), which is one of the most reliable water-budget methods to the region (Scozzafava and Tallini, 2001; Voudouris, 2006). To apply this method it is necessary to determine the maximum water storage of the soil which depends on the soil features, the grain size of the aquifer, the density and the type of vegetation, the water level depth and the ground slope. In this study the maximum water storage in the soil was determined as 100 mm (Voudouris, 2006).

To explore the temporal association of river discharge (Table 1) and rainfall (stations 10-21, Table 2) a consistent yet regionally and temporally sensitive way of ranking the severity of droughts, successfully implemented in southern Romania, was adopted (Stefan et al., 2004). In the first stage, the Gaussian distribution was tested as an adequate fit for the cumulative frequency distribution of monthly rainfall and river discharge.

The Kolmogorov-Smirnov (K-S) test statistic was employed to assess how well the normal distribution fits the data. The K-S test statistics showed that the monthly rainfall totals from all rainfall gauges matched the pattern expected if the data were drawn from a population with a normal distribution. On the other hand, the normal distribution was found to be suitable, according to the K-S test at a 5% significance level, for only three gauging stations (Maronia, Agia Galini and Mythoi) (Table 1). However, because of the convenient properties of the normal distribution, it was selected to fit the cumulative frequency distribution of the two above mentioned hydrological variables.

Assuming a normal distribution, the probability of a value X of rainfall/discharge is:

$$p = m/(n+1) \tag{4}$$

where n is the number of elements of the time series and m is the rank of value X after sorting into descending order.

The 0.65 probability level was chosen in this study to define drought conditions in Crete. According to this criterion, each gauging station (rainfall gauge) analyzed is affected by hydrological (meteorological) drought when the probability of discharge (rainfall) values is higher than 0.65. The same framework was also adopted to study the relationship between precipitation and ET.

The detection of changes in the mean and variability of annual time series of the ratios of precipitation with stream flows (precipitation/discharge) and ET (precipitation/ET) in three stations (19-21) (Table 2) was attempted applying the change-point analysis approach proposed by Taylor (2000). This method iteratively uses a combination of cumulative sum charts and bootstrapping to detect whether a change has taken place.

For each change it estimates a confidence level indicating the likelihood that a change occurred and a confidence interval indicating when the change occurred. This method also controls the change-wise error rate and is robust to outliers. As a result, each change detected is likely to be real.

Furthermore, for the time series of precipitation/discharge and precipitation/ET that did not pass the K-S test or contained outliers, the change-point analysis was performed on the rank of the values instead of the values themselves.

RESULTS AND DISCUSSION

Rainfall-discharge time relationship on an annual basis

A visual inspection of Figure 2 shows that river stream flows and rainfall variability, on year-to-year basis, both exhibit similar variations.

A rather high rate of concurrent drought conditions for each river and its proximate rain gauge (the seasons, the probability for both hydrological variables is greater than the threshold of 0.65) is shown in Table 3**.** This rate was greater than 66% for eight out of nine pairs. The concurrent rate was low only for Geropotamos–Pachia Ammos (33%). A moderate to strong association between the variations of rainfall and discharge is also shown by the relatively high correlation coefficients for most pairs (Table 3).

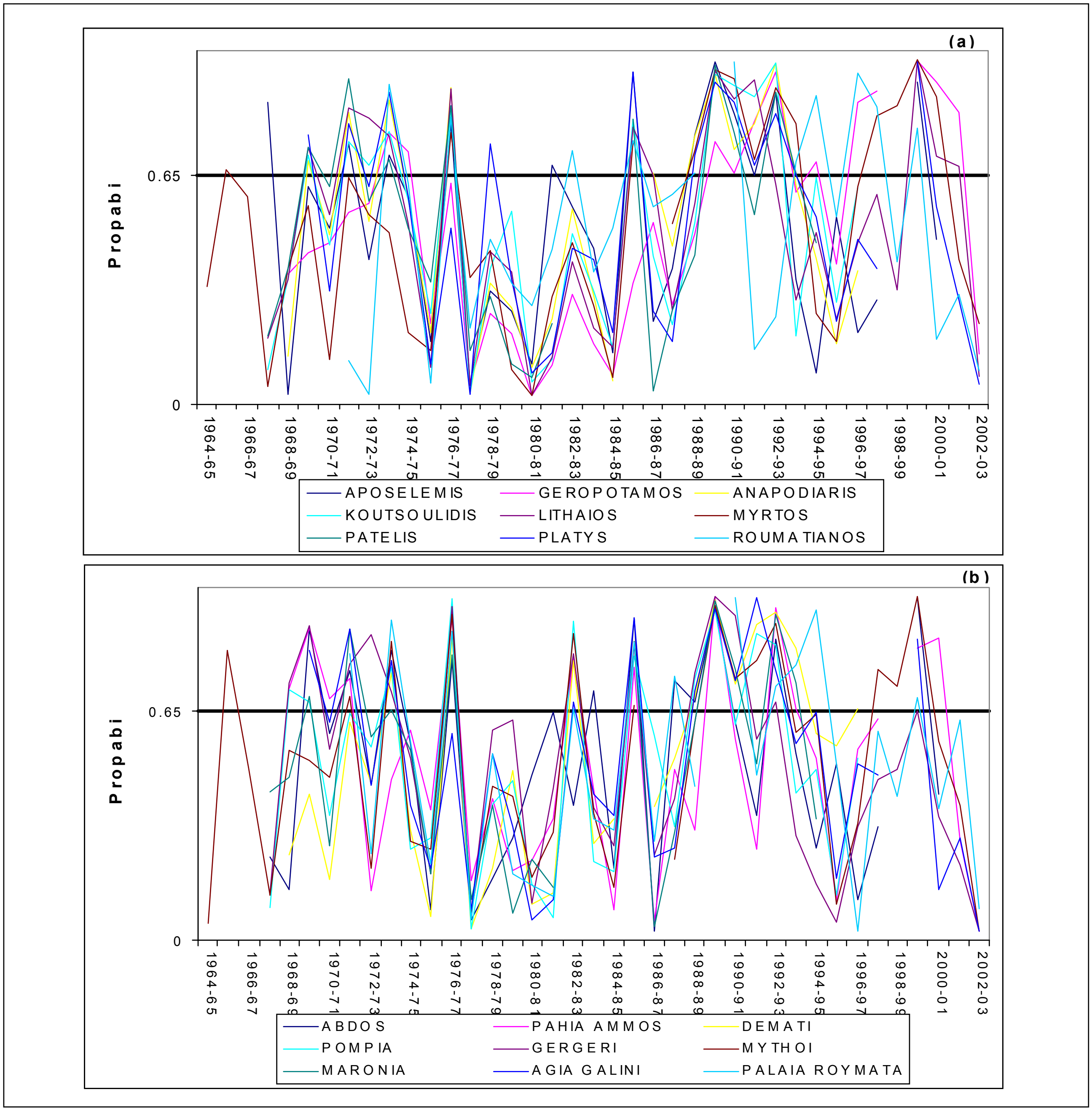

Figure 2. Probability of river discharge (a) and rainfall (b) for stations 1-9 and 10-18, respectively. The probability threshold of 0.65 is also shown.

More specifically, the periods 1969-74 (except for 1970-71), 1976/77, 1985/86, 1988-93, and 1999/00 are characterized by fairly high values of discharge and rainfall probability. Therefore, according to the criterion set for this study, Crete was affected in these seasons both by meteorological and hydrological drought, which was interrupted by short periods of normal or wet years.

During the period 1969–74, eight rivers showed negative discharge anomalies, ranging between 15.7% (Myrtos) and 61.5% (Lithaios), from their corresponding annual means, and only the Roumatianos showed increased discharge by 66.4%. At the same time all rain gauges measured rainfall deficits (by 13.9 %, on average; Table 4) that ranged from 4.9% at Mythoi to 23.3% at Gergeri.

Table 3. Evaluation of temporal association between rainfall and river discharge. The correlation coefficient (r), the probability of concurrent drought conditions, and the time lag are given.

	River – Rainfall gauge	r	Probability of concurrent drought conditions (p>0.65) (%)	Time lag (Months)[¥]
1	Aposelemis - Avdou	0.78*	72.7 (8/11)	+1
2	Geropotamos – Pachia Ammos	0.51*	33.3 (4/12)	-1 / 0
3	Anapodiaris - Demati	0.78*	70.0 (7/10)	-1
4	Koutsoulidis - Pompia	0.83*	80.0 (8/10)	-1 / 0
5	Lithaios - Gergeri	0.72*	66.7 (8/12)	0 / +1
6	Patelis – Maronia	0.90	100.0 (9/9)	-1
7	Myrtos – Mythoi	0.66	76.9 (10/13)	-1
8	Platys – Agia Galini	0.83	90.9 (10/11)	0
9	Roumatianos – Palaia Roumata	0.53*	72.7 (8/11)	-1

* Indicates Spearman correlation coefficient

¥ Negative (positive) sign indicates rainfall (river stream flow) lead.

Discharge mean anomalies were consistent with substantial rainfall deficits measured at all sites by 59 and 57% in seasons 1976/77 and 1985/86, respectively. Severe drought conditions were recorded during 1988–93 (Table 4), when negative stream flow anomalies, varying between 6 and 73%, were found at all gauging stations. This table also demonstrates the response of river discharge to different levels of severity of meteorological droughts. Evidently, and in agreement with the Stefan et al. (2004) conclusion for southern Romania, the influence of the physico-geographical conditions of each basin is reflected in the magnitude of the stream flow anomaly, as well as in the onset of a drought period, which can vary depending on the inertia of the basin to the deficits in rainfall.

The change-point analysis detected shifts in the mean of six out of nine annual time series of (precipitation/discharge). The ratios of Avdou/Aposelemis, Agia Galini/Platys and Palaia Roumata/Roumatianos showed no trends. In four cases for the first change the ratio is diminishing in three of them, and is estimated to have occurred with 97% confidence or more around 1977/78. In six cases a second change in the mean, an increasing shift, was detected with 92% confidence or greater in the second half of the 1980s. Only the ratios of Mythoi/Myrtos presented a change (an increasing shift), occurring around 1984/85, in the year-to-year standard deviation.

Figure 3 shows a graphical presentation of the results of the change-point analysis on the rank of the values of the ratios of Mythoi/Myrtos since the specific time series did not pass the K-S test and contained outliers. The two changes (the increasing shift in the mean and standard deviation in 1985/86 and 1984/85, respectively, are represented by the shifts in the shaded background. The shaded background represents a region expected to contain all the values based on the model that two changes occurred. Since all points fall within this region, this model fully explains the variation in the data.

Table 4. Comparison of hydrological (river discharge) and meteorological (rainfall) drought anomalies (as percentages from their corresponding annual means) for dry seasons.

Period	Hydrological Drought (%)	Meteorological Drought (%)
1969 - 74*	31.5	13.9
1976 - 77	59.1	31.4
1985 - 86	56.9	25.3
1988 - 93	54.3	22.7
1999 - 00	83.6	32.3

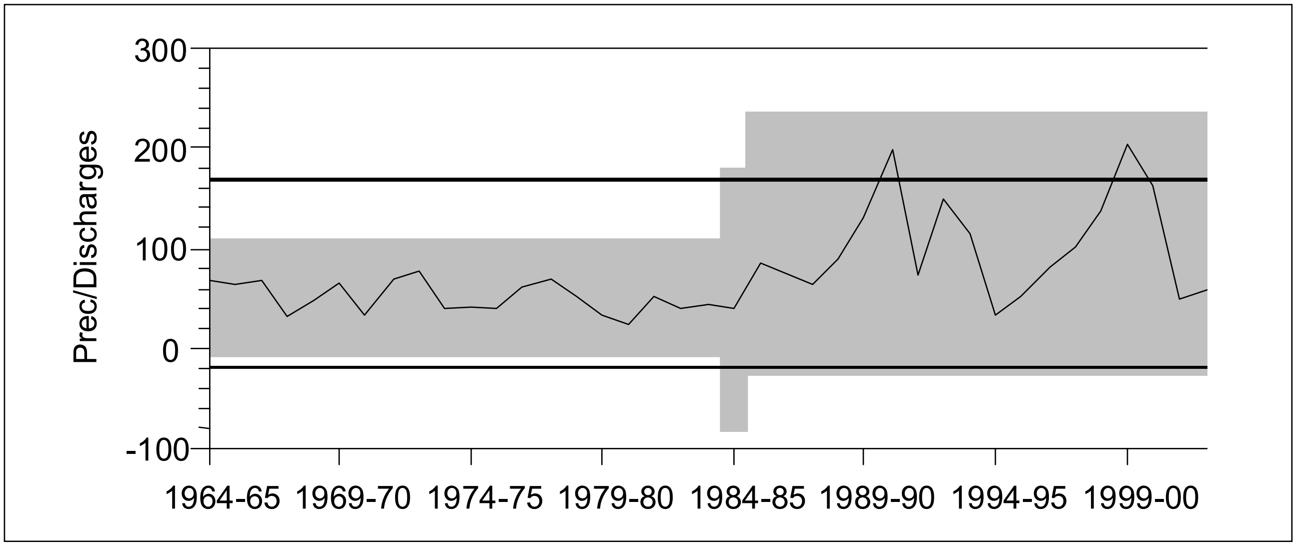

Figure 3. The shifts in the mean and variability of the ratio (precipitation/river discharge) of Mythoi/ Myrtos detected by the change-point analysis. The control limit lines are also displayed.

Rainfall-discharge time relationship on a monthly basis

Several studies have identified a time lag between rainfall and discharge variations (Dettinger and Diaz, 2000; Rimbu et al., 2002; Stefan et al., 2004). For some European rivers the rainfall variations lead to stream flow variations several months later (Stefan et al., 2004). In this study, the time lag between the rainfall variations from each month of the year and the corresponding response in the river discharge was investigated by performing cross-correlation analysis on the filtered normalized monthly anomalies of the two time series using a 1-year running mean filter.

The cross-correlation function between river stream flows and rainfall totals, when all months are taken into account, showed that rainfall leads the discharge variations by one month or less in eight out of nine cases (Table 3). This time lag is probably related to the physical properties of the drainage basins of the rivers in Crete. Only the measured discharge at Potamies (Aposelemis river) were found to precede the rainfall totals measured by the rain gauge in Avdou by one month, due to recharge from groundwater through springs.

The positive correlation coefficients show that the increase in rainfall determines the increase in river discharge (Figure 4). The much smaller than one year time lag found in our study is in agreement with previous studies (Dettinger and Diaz, 2000; Stefan et al., 2004) and suggests that the lag between rainfall and river discharge variation could be neglected at interannual to decadal time scales.

Rainfall-evapotranspiration time relationship on an annual basis

The annual time series of actual evapotranspiration (ET) and rainfall exhibited similar variations (not shown). Moderate rates (>50%) of concurrent cases of meteorological / hydrological drought (low precipitation/low ET) (the seasons, the probability for both hydrological variables is greater than the threshold of 0.65) were identified for the three meteorological stations (Table 5).

The ratio of concurrent cases of high precipitation/high ET (the seasons with a probability for both hydrological variables lower than 0.35) tended to be slightly higher (>56%) for the two stations (Table 5). A moderate association between the variations of rainfall and ET was identified for Chania and Heraklio (as by the respective r values). In the case of Souda the correlation coefficient was lower (47%).

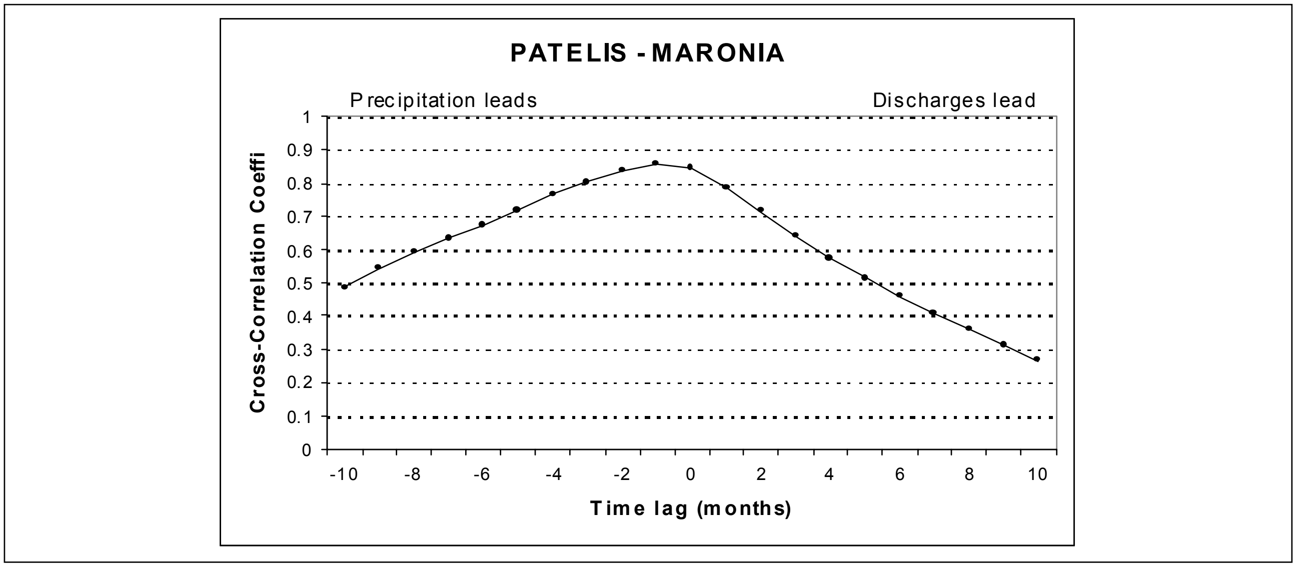

Figure 4. Cross-correlation analysis results between the monthly river discharge of Patelis and rainfall totals from Maronia.

The three stations were affected simultaneously by meteorological/hydrological drought and excessive rainfall/evapotranspiration totals in 6 and 11 seasons, respectively (Table 6). This table demonstrates the response of ET rates to different levels of severity of meteorological droughts.

The average rainfall deficits/surpluses measured by the rain gauges exceeded (in absolute values) the respective reduced/increased rates, from their corresponding annual means, in ET totals in all but one season (except for 1999-00/1986-87, correspondingly).

Furthermore, as for the rainfall-discharge time relationship, the influence of the physical-geographical conditions of each basin is reflected in the magnitude of the ET anomaly which can vary depending on the inertia of the basin to the deficits in rainfall. For example, during the period 1989–90, all rain gauges measured rainfall deficits from their corresponding annual means that ranged from 41% at Heraklio to 44% at Souda. At the same time the respective ET decreased with rates ranging from 12% at Souda to 24% at Heraklio.

The change-point analysis detected no shifts in the mean or variability of the annual time series of precipitation/ET at Souda and Chania. At Heraklio, on the other hand, an increase in the mean and std of the ratio is estimated to have occurred around 1998/99 and 1969/70, respectively.

Rainfall-evapotranspiration time relationship on a monthly basis

As for the rainfall – discharge monthly relationship, the time lag between the rainfall variations from each month of the year and the corresponding response of the estimated actual ET was

Table 5. Evaluation of temporal association between rainfall and ET. The correlation coefficient (r), the probability of concurrent drought cases of meteorological/hydrological drought and excess, and the time lag are given.

	Rainfall gauge	r	Probability of concurrent cases of low Pr–low ET ($p>0.65$) (%)	Probability of concurrent cases of high Pr–high ET ($p<0.35$) (%)	Time lag (Months)
1	Chania	0.64	50.0 (7/14)	64.3 (9/14)	-1[¥] / 0*
2	Souda	0.47	56.3 (9/16)	56.3 (9/16)	0
3	Heraklio	0.63	55.6 (10/18)	76.5 (13/17)	0

* The cross-correlation coefficient was equal for both time lags

¥ The negative sign indicates rainfall leads.

Table 6. Comparison of meteorological/hydrological drought/excess anomalies (as percentages from their corresponding annual means) for dry/wet seasons, respectively.

Period	Low-ET (%)	Low-Pr (%)	Period	High-ET (%)	High-Pr (%)
1965-66	-12.7	-24.6	1959/60	11.1	15.0
1974-75	-12.2	-13.7	1962/63	35.7	74.9
1982-83	-12.3	-32.0	1966/71•	15.3	21.1
1987-90*	-15.6	-33.3	1975/76	3.4	38.7
1992-93	-11.0	-19.9	1981/84£	15.2	24.8
1999-00	-24.7	-18.1	1986/87	22.6	13.9
			1996/97	18.9	25.5
			2002/03	18.1	44.2

*except for the hydrological year 1988-89, •except 1967/68 and 1969/70, £except 1982/83.

investigated by performing cross-correlation analysis on the filtered normalized monthly anomalies of the two time series with a 1-year running mean filter.

The cross-correlation analysis between evapotranspiration and rainfall totals, when all months are taken into account, identified zero time lags for two stations (Table 5). Only the rainfall totals measured by the rain gauge at Chania were found to precede the computed ET by zero to one month. These results suggest that the lag between precipitation-ET variation could be neglected at interannual to decadal time scales.

CONCLUSIONS

From the analysis of hydrological data in Crete island, the following conclusions can de drawn:

- A greater than 66% rate of concurrent drought conditions for each river and its proximate rain gauge was found. In dry hydrological years river runoff decreased by 31 to 84%, compared to its mean annual rate.

- A moderate to strong association between the variations of rainfall and discharge is also shown by the relatively high, for most pairs, correlation coefficients (coefficient r varied from 0.51 to 0.90).

- The change-point analysis detected increasing shifts in the mean of six out of nine annual time series of precipitation/discharge. These changes are located in the second half of the 1980s. In three cases a second change, a diminishing in the rate, is estimated to have occurred around 1977/78. Only one site presented a change (an increasing shift), occurring around 1984/85, in the year-to-year variability.

- Moderate rates (>50%) of concurrent cases of meteorological/hydrological drought (low precipitation/low ET) were identified for the three meteorological stations. In dry hydrological years actual ET decreased by 12 to 25%, compared to its mean annual rate.

- A moderate association between the variations of rainfall and ET was identified for two locations (r was equal to 0.63 and 0.64, respectively). For Souda the correlation coefficient was lower (0.47).

- The change-point analysis detected an increase in the mean and std of the annual time series of precipitation/ET at one (Heraklio) out of three locations. These changes are estimated to have occurred around 1998/99 and 1969/70, respectively.

- The time lag between the variations of rainfall with river flow variations ranged from 0 to 1 month. Zero time lag was estimated from the cross-correlation analysis between ET and rainfall totals.

Future investigations of the sustainable management of water resources in Crete island would benefit by meteorological, hydrological, and water quality data monitoring, land use monitoring, groundwater table measurements and computer modeling to simulate the hydrological cycle.

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