Regional analysis of climate and bioclimate change in South Italy

A. Capra, P. Porto & B. Scicolone
Department of Agro-forestry and Environmental Sciences and Technologies, Mediterranean University of Reggio Calabria, Italy

Abstract

In this paper, monthly values of rainfall (*P*) and temperature (*T*) recorded in Southern Italy (Calabria and Sicily) during the period 1921-2000 are investigated. In particular, a series of 211 raingauge and 53 temperature stations are analysed for evidence of trend by using the linear regression and the Kendall non-parametric test. The tests are applied at a seasonal and annual scale; a spatial analysis is also carried out at both a regional and sub-regional scale in order to check the effect of different sub-areas on these trends. An additional investigation useful for checking the climate change effects on vegetation is also included analysing bioclimatic parameters such as evapotranspiration and aridity index. The results obtained confirmed, for the two investigated regions, the importance of the climatic analysis carried out at a regional scale. In fact, the tests showed for both the *P* and *T* records a strong difference between the two investigated regions. In particular, the total annual *P* showed a decreasing and increasing trend with -344 and 197 mm/100 years respectively in the Tyrrhenian and Ionian sub-regions of Calabria and a decreasing trend with -179 mm/100 years in Sicily. A decreasing trend is evident in the Tyrrhenian sub-region for the mean annual values of T_{max} (-3.2 °C/100 years) and T_{min} (-2.9 °C /100 years); a different trend is shown in the Ionian sub-region where the mean annual values of *T* showed an increase of 2.2 and 0.9 °C /100 years for T_{max} and T_{min} respectively. In contrast, a clear increasing trend (1.8 and 2.2 °C /100 years) is shown for both T_{max} and T_{min} in Sicily. A detailed analysis involving the calculation of 10-year moving averages, showed a significant change of trending after the 1950s for *P* and after 1970s for *T*.
Keywords: climate change, precipitation, temperatures, bioclimatic parameters.

1 Introduction

It has been observed that during the last 100-150 years the Italian climate has changed and it has resulted in a rise of temperature and aridity. According to Brunetti et al. [1], during the period 1865-2000, the mean annual temperature (T_{ya}) indicates a 0.4°C/100 years rise within the northern areas (N) of the country (continental zone) and a 0.7°C/100 years rise in the central (C) and southern (S) Italy (peninsular zones). More particularly, at seasonal scale, the slopes of the regression line are greater during the winter season, ranging from 0.7°C/100 years (N) to 0.9°C/100 years (S), while for the summer season they are lower and in some cases not significant. A negative trend of the annual rainfall (P_y) is evident within both N and S areas with a slope equal to -47 mm/100 years and -104 mm/100 years respectively which mean, for the investigated period, 7% of the mean rainfall for the northern area and 18% for the South. This decreasing trend occurred particularly after 1950 since then the number of wet days (N_P) has also decreased. The maximum annual temperature (T_{ymax}) series show a slope of the regression line ranging between 0.4°C/100 years for N and 0.6°C/100 years for S while the minimum annual temperature (T_{ymin}) series show slope values between 0.3°C/100 years for N and 0.5°C/100 years for S. According to Brunetti et al. [1], the most important contribution to this positive trend is due to roughly the last 20 years (before 1996) for N and to roughly the last 50 years for S. In respect to extreme events, it has resulted an increase of rainfall intensity within both N and S areas [1], [2] and a tendency toward an increase in drought [3], [4], [5], [6].

Other investigations carried out in Italy [4], [7] showed a different behaviour of the same climatic series if a subdivision of the N and S areas into smaller sub-regions is taken into account.

For this reason, it seems necessary to investigate the climate change on a regional scale where different geographical factors (e.g. distance from the sea, elevation, aspect) are likely to influence the magnitude of these trends. Such investigation can be useful not only in terms of improving scientific knowledge but also to provide the Italian government with useful information in order to make the right choices in planning future activities.

Calabria and Sicily (Fig. 1) are two regions located in South Italy and are particularly prone to be investigated at local scale because of their geographic characteristics and local orographic features. In particular, Calabria (Ca) is a narrow (with a width ranging from 30 to 95 km) and long peninsula extending from North to South for about 250 km; a mountain range (Apennine) runs in latitude and divides the region into two opposite areas: the Tyrrhenian and the Ionian zones. This mountain range is located almost perpendicularly to the direction of the dominant moisture-bearing winds and for this reason it causes a very strong variability in terms of rainfall and temperature patterns considering also the different altitudes and aspects [8]; that is why it is easy to find flat and semi-arid coastal areas (T_{ya} and P_{ya} equal to 17.4°C and 683 mm respectively) as well as mountain zones with T_{ya} equal to 9.1°C and P_y equal to 1242 mm (the highest in the South). Locally, the annual rainfall P_y ranges from 1107 mm over the Tyrrhenian area (CaT) to 945 mm over the Ionian zone (CaI).

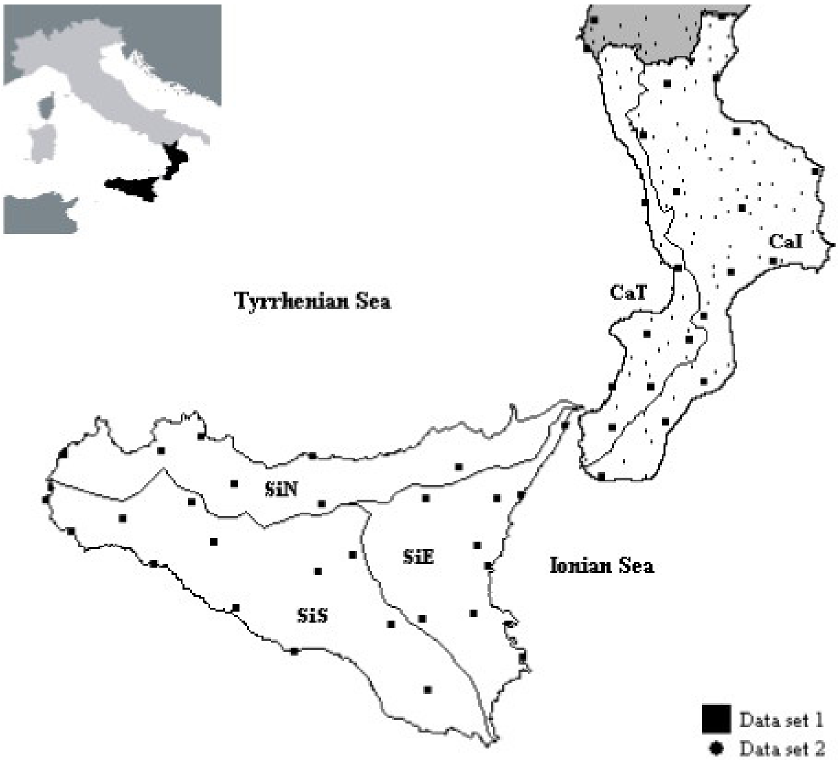

Figure 1: Location of investigated regions, sub-regions and weather stations. The two Calabrian sub-regions named Tyrrhenian and Ionian are marked with CaT and CaI respectively; SiN, SiS, and SiE represent North, South, and East zones of Sicily.

Sicily (Si) is the largest island of the Mediterranean Sea. According to traditional geographical distinctions for making sub-regional analysis, Sicily was divided into three homogeneous sub-regions (North, East, and South in Fig. 1). Each sub-region is separated from the others by mountain ranges and for this reason the rainfall pattern is different from area to area. Locally, the annual rainfall P_y is 591 mm in the South area (SiS), 735 mm over the East area (SiE) and 717 within the North sub-region (SiN). Because of its particular geographic location in the centre of the Mediterranean Sea, Sicily was often investigated as a key region in order to explain the climate evolution within the Mediterranean basin [8].

To date, the studies carried out in this area are limited on a few stations (5 for temperatures and 11 for rainfalls – see Brunetti et al., [1], [2]) and for the reasons explained above it could be of interest to extend this investigation on a greater number of stations in order to give useful information on climate change in Mediterranean areas.

The study proposed here aims at analysing temperatures and precipitations over the two regions (Calabria and Sicily) for the period 1921-2000, using weather stations with high spatial resolution. The analysis also includes the use of bioclimatic indexes because in agro-forestry environments the consequences of climatic change depend on the interaction between temperatures (maximum, T_{max}, minimum, T_{min}, and mean, T_a) and rainfalls (P_m), that can be summarised by appropriate indexes which account for aridity and plant water demand.

2 Data and methods

This paper investigates monthly values of temperature (T_{max}, T_{min}, and T_a) and rainfall (P_m) collected by the Italian Hydrographic Service (IHS) during the periods extending respectively from 1926 to 2000 and 1921 to 2000. The IHS database concerning the two investigated regions includes about 120 temperature and 600 raingauge stations.

Even if a considerable number of stations was considered, many of these sites were neglected because long periods of malfunctioning.

The analysis was firstly carried out on a dataset including 53 temperature and raingauge stations (25 of which in Ca and 28 in Si). These sites were selected considering the dataset continuity as well as geographic and altitude representativeness; datasets with more than 20% of lacks (with some exceptions) were also neglected.

An additional database including only rainfall series (monthly, seasonal and annual) and composed of 158 Calabrian stations was also used in the analysis in order to get more details about the spatial variability over the investigated regions. For this database an additional analysis involving the number of wet days, N_p, was carried out for the period 1951-2000. The analysed weather stations are located as in figure 1.

Although no specific tests were applied, we suppose that the series used here are homogeneous because they were collected using the same criterion that did not change during the analysed period; also, specific tests involving Sicilian data only, did not show particular anomalies due to malfunctioning [6].

The monthly values of T_{max}, T_{min}, T_a and P_m were also used to calculate the following indexes:

a) the monthly reference evapotranspiration, ET_{0m}, estimated by Hargreaves formula [9] that, for sites where no direct radiation measurements are available, assumes the following form:

$$ET_{0m} = 0.0023\, Ra\left(T_a + 17.8\right)\sqrt{T_{\max} - T_{\min}}\; d \qquad (1)$$

where Ra (mm d^{-1}) is the extraterrestrial radiation, calculated on the basis of latitude and calendar day [10]; d is the number of days of the month. The Hargreaves equation was chosen because it represents a good compromise between simplicity (because based on temperature data only) and goodness of results in many environments [10] including Sicily [11];
b) the aridity index, AI, calculated using the following equation:

$$AI = \frac{P_y}{\sum_{j=1}^{12} ET_{0m,j}} \quad (2)$$

The monthly series of T_{max}, T_{min}, T_a and P_m were also analysed at sub-regional scale within the two Calabrian (CaT and CaI) and the three Sicilian (SiN, SiE and SiS) homogeneous sub-regions.

Seasonal and annual mean values of temperature and rainfall for each sub-region were checked with the Mann-Kendall non-parametric test, as described in Hirsch *et al.* [12] to look for a trend. The slope of the trends was calculated by least-square linear fitting. An additional analysis involving the 10-years running averages was carried out with the aims to show the long period tendencies.

The indices ET_{0m} and AI were analysed by splitting the study period into two sub-periods: from 1926 to 1962 and from 1963 to 2000. For each period, we calculated the slope of the regression lines and the percentage of stations for which the t-test [12] at the 0.05 level was significant.

3 Results

3.1 Yearly and seasonal temperature and precipitation analysis

The mean values b of the calculated slopes of the regression lines for the investigated stations are listed in Table 1 together with the proportion of weather stations for which the Mann-Kendall test showed significant values (at the 0.05 level of significance).

The T_{ya} values showed increasing trends in all zones and sub-zones, with b values ranging from +0.1 to +2.2 °C/100 years, with the only exception of CaT (where b = - 1.4 °C/100 years). In general, the b values calculated for Si were greater than those resulted in Ca. The higher increments occurred during the winter season in Si and during the spring in Ca where T_{ya} also showed a decreasing trend in autumn and, only for CaT, in summer and winter.

The analysis carried out for T_{min} showed in most cases b values greater than those related to T_{max}. The T_{min} increase was similar in all seasons; conversely, the T_{max} increase was greater in autumn and in winter.

At seasonal scale, the analysis showed the highest b values in Si and in particular for SiS.

The percent of weather stations for which the Mann-Kendall test (K, %) showed significant values was always greater than 50% for the annual values of T_a, T_{max} and T_{min}. At seasonal scale, the highest percentages occurred in Si, with values greater than 80% particularly for T_{min}.

Table 1: Mean values of linear regression coefficients (*b*), and percent of stations with significant trend (Kendall's test, K, %) for temperatures (T) and rainfalls (P) of Sicily (Si) and Calabria (Ca).

	zone	T						P	
		T_{max}		T_a		T_{min}			
		b	K	*b*	K	*b*	K	*b*	K
Spring	Si	1.1	39	1.7	46	2.3	71	-7	4
	SiN	1.2	29	1.4	43	1.6	57	2	0
	SiE	1.1	22	1.8	56	2.5	89	-30	11
	SiS	1.0	58	1.8	42	2.5	67	5	0
	Ca	1.4	44	2.1	40	0.8	56	-43	15
	CaT	-1	43	2.3	43	-1.2	43	-62	13
	CaI	2.7	44	0.5	22	1.1	39	7.9	0
Summer	Si	1.3	29	1.9	57	2.4	75	8	7
	SiN	1.7	29	1.5	43	1.3	57	3	0
	SiE	1.2	22	2.0	56	2.7	89	2	0
	SiS	1.2	33	2.0	67	2.9	75	15	17
	Ca	0.7	48	1.4	36	0.3	56	37	22
	CaT	-3.2	43	-0.5	43	-0.3	43	30	42
	CaI	2.1	50	0.1	33	1.1	33	106	21
Autumn	Si	2.1	54	1.9	68	1.6	64	-82	36
	SiN	1.5	29	1.4	43	1.4	57	-80	29
	SiE	2.1	67	2.1	78	2.0	87	-97	22
	SiS	2.4	58	2.0	75	1.5	67	-72	50
	Ca	1.1	44	-0.4	56	-0.1	32	-128	39
	CaT	-0.1	29	-3.9	71	-2.6	14	-135	40
	CaI	1.9	44	-0.4	50	0.4	11	43	1
Winter	Si	2.8	71	2.6	75	2.5	68	-98	57
	SiN	1.8	43	1.8	43	1.7	43	-105	57
	SiE	2.6	89	2.6	89	2.6	78	-91	56
	SiS	3.4	75	3.1	83	2.8	75	-100	58
	Ca	1.1	28	0.8	28	0.6	48	-139	37
	CaT	-1.5	29	-1.0	29	-1.7	43	-176	47
	CaI	2.2	22	0.6	22	1.1	28	41	0
Year	Si	1.8	61	2.0	57	2.2	79	-179	43
	SiN	1.5	57	1.5	57	1.5	71	-181	43
	SiE	1.7	56	2.0	89	2.4	89	-212	44
	SiS	2.0	67	2.2	75	2.4	75	-153	42
	Ca	1.1	56	0.1	56	1.1	68	-272	47
	CaT	-3.2	43	-1.4	57	-2.9	43	-344	49
	CaI	2.2	51	0.2	44	0.9	33	197	1

b = °C/100 years for T and mm / 100 years for P; N = North; E = East; S = Sud; T = Tyrrhenian; I = Ionian.

The annual values of rainfall showed decreasing trends in all zones and sub-zones, with *b* values ranging from -153 to -344 mm/100 years; the decrease was greater for Ca while it covered about 21% of the mean annual rainfall of the investigated period for both the regions. Where *b* was positive (CaI) the percent of stations with significant trends was very low (1%) and can be neglected.

Negative trends occurred in autumn and winter, with *b* values ranging from -72 to -176 mm/100 years, with the only exception of CaI. During these seasons, although almost all the stations showed decreasing trends, these were significant, for more than 50% of the sites, only for winter rainfalls of Si.

A greater variability occurred for spring rainfalls, while the summer ones showed positive values of *b* (between 2 and 106 mm/100 years).

The rainfall decreasing trend seems to depend principally on the decrease of N_p (number of wet days); in particular, for Ca, during the period 1951-1998, N_p decreased of 32 days (*b* = 67 days/100 years); this decrease occurred especially during winter and spring.

Referring to long-period tendencies, the 10-years running averages showed complex and different behaviours from zone to zone and between the investigated climatic variables. T_{ya} showed a strong increase since the 70s (Fig. 2) for Si; the trends are very similar from zone to zone. Conversely, the corresponding trends in Ca, since the same period, seem to be decreasing (Fig. 2). In this case, if the T_{ay} series are divided into two sub-periods of equal duration, it can be seen that in CaI, *b* is increasing during the first sub-period (1926-1962) and almost equal to zero during the second one (1963-2000); in CaT, *b* was almost equal to zero during the first period and negative during the second one.

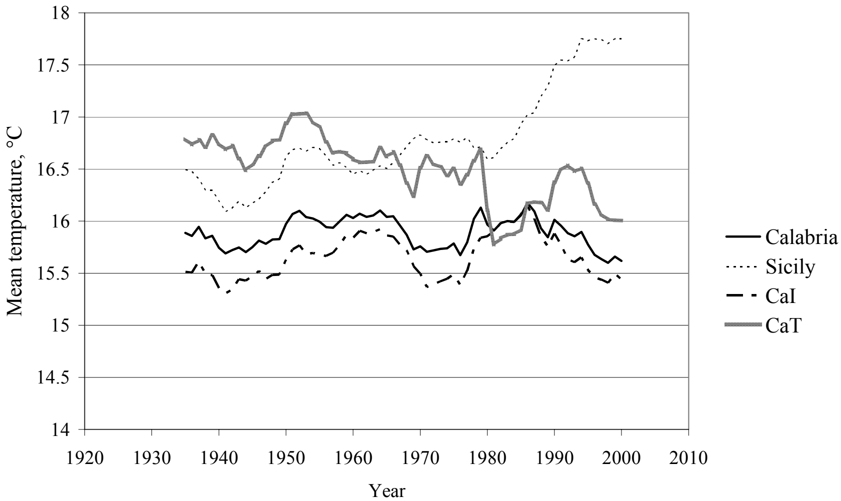

Figure 2: Ten-years running averages of annual mean temperature.

P_y showed a decreasing trend, more clearly since the 50s, in both Si and Ca. Even in this case, the 10-years running averages showed similar behaviours within the Sicilian sub-regions; conversely, in Ca the regional results seem to hide the increasing trend of CaI (Fig. 3).

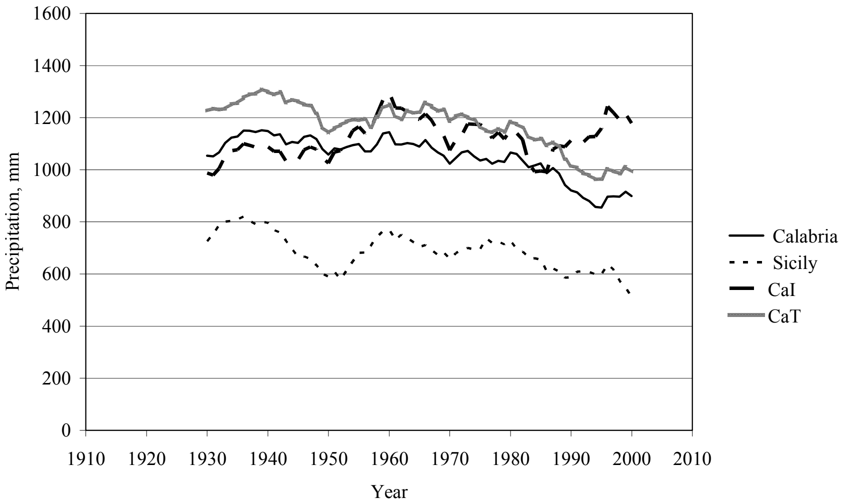

Figure 3: Ten-years running averages of annual precipitation.

Table 2: Mean linear regression coefficients (*b*), and percent of stations with significant trend (t-test, %) for Evapotranspiration (ET_0) and Aridity index (*AI*) for Sicily in the sub-periods 1926-62 and 1963-2000.

		ET_0					*AI*
		Spring	Summer	Autumn	Winter	Year	
1926-62	*b*	29	82	21	22	154	-0.2
	t, %	25	25	25	25	25	18
1963-2000	*b*	58	35	7	40	150	-0.3
	t, %	50	25	39	46	46	14

b = mm/100 year for ET_0; $mm \cdot mm^{-1}$/100 years for *AI.*

3.2 Bioclimatic indices analysis

The annual values of ET_0 in Si showed *b* values always positive and almost the same for the two investigated sub-periods during which its increase was about 5% of the ET_0 values calculated for the same sub-periods. At seasonal scale, the greatest rise occurred in summer, during the first sub-period (1926-1962) and in spring during the second one (1963-2000).

The proportion of weather stations that showed significant trends (*t*-test at 0.05 level of significance) was greater during the second sub-period and this behaviour can be explained by the greater temperature increase occurred during the same period. The aridity index *AI* showed a decrease in both the sub-periods, particularly during the second one (1963-2000), where it assumes a mean value equal to 0.62 (typical for sub-humid dry climate) that is less than the first period where its calculated mean value resulted equal to 0.70 (typical for sub-humid climate). The trends are significant (at the 0.05 level) for less than 20% of the considered weather stations.

4 Conclusions

The analysis carried out in this study which involved temperature and precipitation data covering a period of about 80 years, showed an increase of temperature (ranging from 0.1 and 2.2°C/100 years for the mean annual temperature) and a decrease of precipitation (ranging from 153 to 344 mm/100 years for the annual rainfall) over the two investigated regions (Calabria and Sicily) located in South Italy. The precipitation decrease can be explained by the decrease of the number of wet days N_P according to other studies performed in different Italian regions. The calculated values of evapotranspiration ET_0, which accounted for mean (T_a), maximum (T_{max}) and minimum (T_{min}) values of temperature, showed an increasing trend which was lower than that related to the temperature because T_{max} and T_{min} did not increase with the same magnitude.

The aridity conditions are not encouraging during the analysed period: the calculated Aridity Index (*AI*) showed values which tend to decrease from a first sub-period (1926-1962) to a second one (1963-2000). This resulted in a climate change in Sicily from a sub-humid climate to a sub-humid dry climate.

Because of the geographic location and the particular orographic features of the two investigated regions which extend over 3° of latitude, a strong difference in terms of climate change occurred. These main differences can be summarised as follows: a strong increase in temperature has occurred in Sicily since the 1970s, while in Calabria the same variable showed steady values or a light decrease; T_{max} and T_{min} values have clearly decreased during all the seasons over the Calabrian Jonian sub-region (-3.2 e -3.9 °C/100 years respectively for T_{max} and T_{min}); rainfalls have increased over the Calabrian Ionian sub-region (197 mm/100 years for P_y).

The overall results showed the importance of the climate change analyses at a regional scale and provide the Italian authorities with useful information to begin to assess the impacts of such climate changes on human activities.

References

[1] Brunetti, M., Buffoni, L. & Mangianti, F., Temperature, precipitation and extreme events during the last century in Italy, *Global and Planetary Change*, 40, pp. 141-149, 2004.

[2] Brunetti, M., Buffoni, L., Maugeri & M, Nanni, T., Trend of minimum and maximum daily temperatures in Italy from 1865 to 1996, *Theor. Appl. Climatol.*, 20, pp. 1017–1031, 2000.

[3] Capra, A., Indelicato, S., Li Destri Nicosia, O. & Scicolone, B., Evaluation de la sécheresse d'aprés les données de précipitation. Une application au Sud d'Italie, *Proc. of the 16th European Regional Conf., ICID*, Budapest, Hungary, June, pp. 41-51, 1992.

[4] Capra, A., Li Destri Nicosia, O. & Scicolone B., *Application of fuzzy sets to drought classification*, *Proc. of the 2nd Int. Conf. On Advances in Water Resources Technology and Management*, Eds. G. Tsakiris & M.A. Santos, Balkema, Rotterdam, pp. 479-483, 1994.

[5] Piccarreta, M., Capolongo, D. & Boenzi, F., Trend analysis of precipitation and drought in Basilicata from 1923 to 2000 within a southern Italy context, *Int. Journal of Climatology*, 24, pp. 907-922, 2002.

[6] Rossi, G. & Cancelliere, A., Problemi e prospettive del monitoraggio e delle mitigazione della siccità*, Editoriale Bios, Cosenza, Quaderni di Idrotecnica*, pp. 9-44, 2002 (in Italian).

[7] Capra A., Malara, S.L. & Scicolone, B., (2004), Analisi delle temperature e delle piogge mensili in Calabria nell'ultimo cinquantennio*, Economia Montana- Linea Ecologica*, 3, pp. 31-36, 2004 (in Italian).

[8] ENEA, Cambiamenti climatici e rischi di siccità e desertificazione in area mediterranea ed in Sicilia*, Progetto speciale clima globale*, Roma, Italy, giugno, 2002 (in Italian).

[9] Hargreaves, G.H. & Samani, Z.A., Reference crop evapotranspiration from temperature. *Transactions of the ASAE*, 1(2), 96–99, 1985.

[10] FAO, Crop evapotranspiration. Guidelines for computing crop water requirements, *FAO Irrigation and drainage Paper*, 56, 1998.

[11] Di Stefano, C. & Ferro, V., Estimation of Evapotranspiration by Hargreaves Formula and Remotely Sensed Data in Semi-arid Mediterranean Areas, *J. Agric. Engng Res*., 68, 189–199, 1997.

[12] Hirsch, R.M., Helsel, D.R., Cohm, T.A. & Gilroy, E.J., Statistical analysis of hydrological data, *Handbook of Hydrology*, Ed. Maidment, D.R., McGraw-Hill, pp. 17.1-17.55, 1993.