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Rainfall and drought in southern Italy (1821–2001)

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Abstract Southern Italian monthly rainfall and temperature data for the period 1821–2001 were analysed statistically. The data were selected for 126 raingauges with the most complete time series. The main study period for which reliable and gap-free annual data are available was 1921–2001. During this period a widespread decreasing trend in annual rainfall was observed for over 96% of the area. This trend was most severe where mean annual rainfall was highest. A decreasing trend of less than –9 mm year^{-1} was found in the worst case. Analysis of the historical series showed that this trend became more apparent after 1980, the period subjected to two serious droughts (1988–1992 and 2000–2001). In particular, a significant deficit in winter rainfall was found after 1980. Monthly temperatures were also considered. Net rainfall was calculated as a function of monthly rainfall and temperature. Negative trends and the effects of recent droughts were enhanced in terms of net rainfall.

Key words climate; drought; rainfall trends; time series

INTRODUCTION

Southern Italy has been hit by dramatic and frequent droughts in the last two decades. The prolonged unavailability of water resources or a significant water resources deficit was the reason inhabitants were short of water, there were dramatic economic losses for industry and agriculture was in difficulties.

This study is based on monthly rainfall and temperature data, extending the results of previous work which only dealt with annual rainfall data (Cotecchia *et al.*, 2003). It attempts to offer answers to questions concerning the causes of these droughts, in terms of the modification of the hydrological cycle in time and space domains, focusing on the natural availability of water resources, independent of the human ability to tap and to manage these resources.

DATA AVAILABILITY AND SELECTION

The Italian Hydrological Service (*Servizio Idrografico e Mareografico Nazionale*, SIMN) was operating 817 raingauges in Campania, Apulia, Basilicata and Calabria before 1970. Of these gauges, 458 were installed before 1925 and 40 were installed before 1900 (SIMN, 1976). Not all of these gauges have operated continuously.

The selection of the available rainfall time series was necessary in order to obtain a sufficient gauge density and a spatial continuity in the variables analysed, covering a long period with the minimum number of data gaps. The first gauges selected were

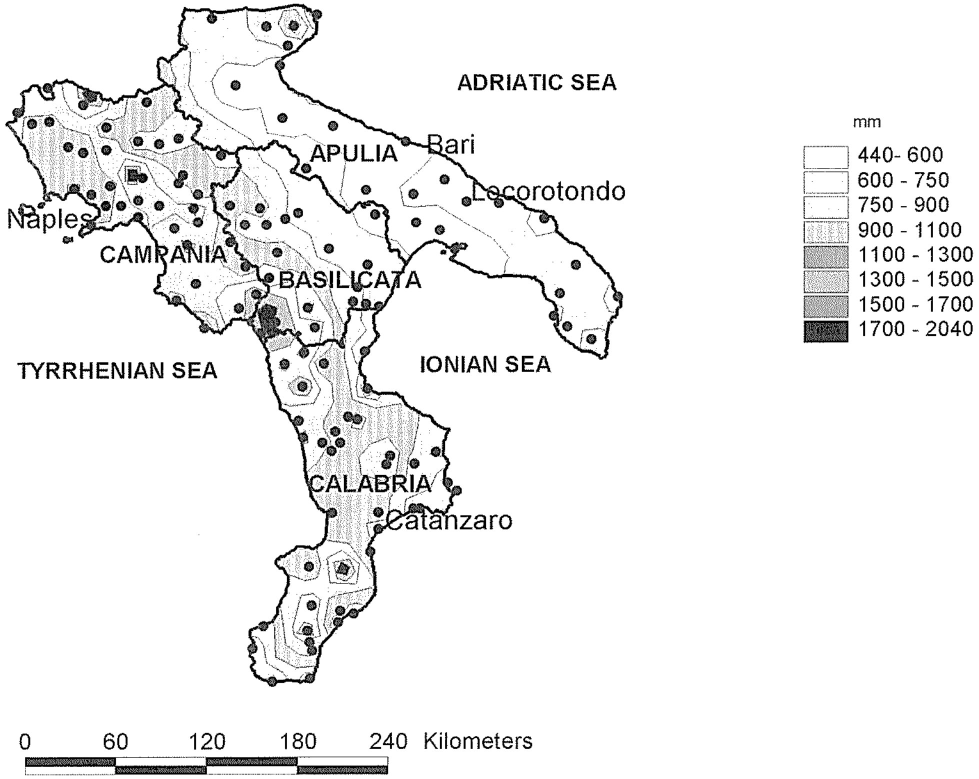

Fig. 1 Studied area, selected raingauges and average annual rainfall (1921–2001).

those dating from 1900. However, very few of these stations have worked continuously up to the present. A selection was made from the gauges installed from 1900 to 1925. Finally, 126 gauges were selected—the ones with the minimum gap percentage in their time series. They included 40 raingauges in Campania, 40 in Calabria, 26 in Apulia, 20 in Basilicata (Fig. 1), with 22 of them also recording temperature. Data were obtained from the annual SIMN publications (SIMN 1916–2000). The most recent records, generally measured by telemetering gauges, were acquired thanks to Naples, Bari and Catanzaro SIMN departments. Data before 1915 were collected by Eredia (1918). All the available data from the period 1821 to 2001 were collected. The time series can be considered almost complete only from 1921 to 2001, the so called *Main Study Period* (MSP).

Although the selection included the gauges with the most continuous time series, some short gaps were however present in the database. Gaps were filled using multiple regressions based on a selection of the best correlated data series of the nearest gauges. The multiple regressions were performed on the normalized deviation of annual rainfall from the *Mean Annual Precipitation* (MAP), considering the best correlated time series ($r > 0.7$) of nearest gauges (up to six).

The first result was the MAP plot of the study area for MSP (Fig. 1). This map was obtained by interpolating gauge MAPs in a GIS environment, operating with a 1-km spaced grid. For each cell, a value has been calculated by weighting the data from the

Table 1 Rainfall and regions. For each region the mean is determined considering the MSP: annual precipitation (MAPR, mm), annual inflow (MAIR, Mm^3), precipitation trend (TR, mm year^{-1}), precipitation variation (PVR, mm) due to the trend and to the duration of MSP.

Region	MAPR	MAIR	TR	TR/MAPR	PVR	PVR/MAPR
Apulia	644	12500	–0.80	–0.12%	–65	–10.1%
Basilicata	893	8900	–1.81	–0.20%	–145	–15.9%
Calabria	1043	15700	–2.87	–0.28%	–230	–22.0%
Campania	1118	15200	–2.44	–0.22%	–196	–17.5%

12 nearest gauges, with weights proportional to the inverse squared distances. The procedure and the grid characteristics were not changed for the remaining calculations. The average rainfall map allows verification of the completeness of the compiled database: the correct reproduction of local rainfall spatial variation, as shown in the literature (SIMN, 1958), is indicative of sufficiency of the spatial coverage of the database and of the reliability of the interpolation procedure for the spatial variables examined.

The *Mean Annual Precipitation of Region* (MAPR) was calculated from the MAP plot (Table 1).

AVERAGE RAINFALL TRENDS 1921–2001

The least squares line of best fit was determined for each rainfall time series in the MSP. The slope of this line, in terms of the angular coefficient, is representative of the annual rainfall trend. An increasing trend was only found for 12 stations in the 126 series selected; the maximum observed slope is about 2.5 mm year^{-1}. Decreasing trends were observed for 114 series (90%); the minimum is about –9 mm year^{-1}. If a 5% significance level is considered for correlation coefficients, 60 negative trends are found *vs* only 2 positive trends.

Some 96% of the study area exhibits a negative trend (Fig. 2). If we define as relevant a trend higher than 1 mm year^{-1} in absolute terms, the negative trend is relevant in 70% of the area, the positive trend in only <1%.

A Mann-Kendall test was performed for highlighting systematic trends in time series (Mann 1945; Kendall 1976). The variable $T(k)$, given by the following expression:

$$T(k) = \sum_{i=2}^{k} \sum_{j=1}^{i-1} \operatorname{sgn}(z_i - z_j)$$

where z_i is the annual rainfall of the considered gauge and $T(k)$ ($k = 81$ in our case) is distributed, if the data do not show a trend, with a null mean and a variance given by the expression:

$$\operatorname{Var}(T) = \frac{k(k-1)(2k+5)}{18}$$

The result of test calculation, normalized to the respective standard deviation, highlights a negative trend over 98% of the area, with the Mann-Kendall variable lower

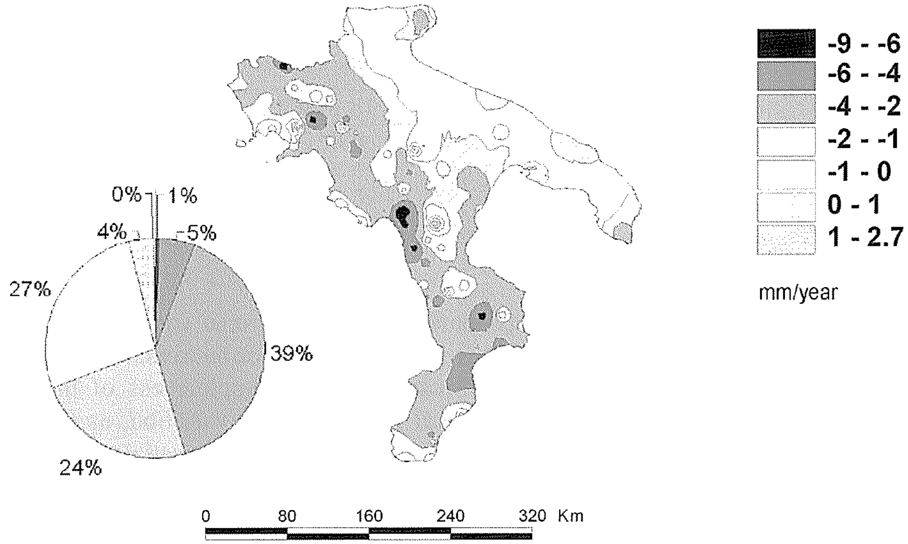

Fig. 2 Trend of annual rainfall as angular coefficient of regression line (1921–2001) and pie chart of rainfall trend classes and interested area

than the average for more than one standard deviation over 75% of the area, and for more than two standard deviations over 39%. The geographical distribution of significant deviations of the test variable confirms the trend map results. It is beyond doubt that there is a relevant and generalized decreasing trend in rainfall for the period 1921–2001.

In a GIS environment, where both average rainfall and trend are associated to each cell, it is possible to classify cells in rainfall classes, calculating the average trend for each class. It can be observed that the generalized decreasing trend is correlated to the MAP and is worse where the MAP is higher. Low MAP areas—less than 600 mm, mostly located in Apulia—show a spatial average decreasing trend close to –0.75 mm year^{-1}. The middle MAP areas (700–1300 mm) show a decreasing trend –1.4 to –2.8 mm year^{-1}. The average decreasing trend rises to –6.5 mm year^{-1} where the MAP is highest (1500–2000 mm).

If the MAP total is quantified against the trend, it can be observed that only 2% of total precipitation, as the spatial total, occurs on areas where the rainfall trend is positive, and 87% on areas with decreasing trend lower than –0.5 mm year^{-1}. In particular, 50% of MAP total is associated to negative trends lower than –2.5 mm year^{-1}. In Calabria and Campania, the most rainy regions, the 1921–2001 decrease is about 20% of MAP spatial total.

ANALYSIS BY DECADE: 1921–2001

For each gauge the deviations of the 10-year averages were calculated from the MAP. The 1930s, the 1950s (with the exception of Campania) and the 1970s were generally rainy; in contrast to a relevant precipitation deficit which has been highlighted everywhere during the latest two decades (Figs 3–4).

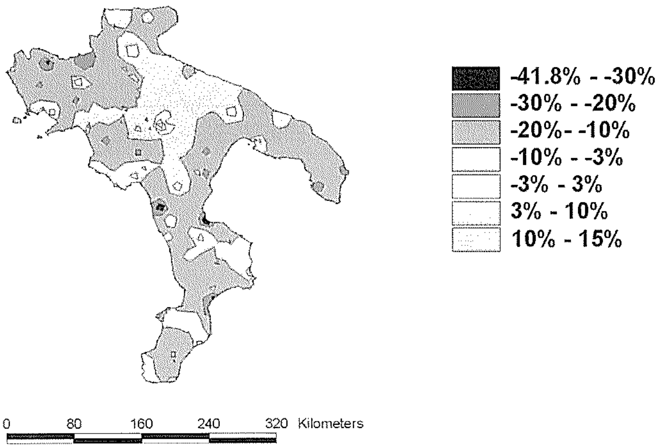

Fig. 3 Deviation of 1980s decade rainfall average from 1921–2001 average.

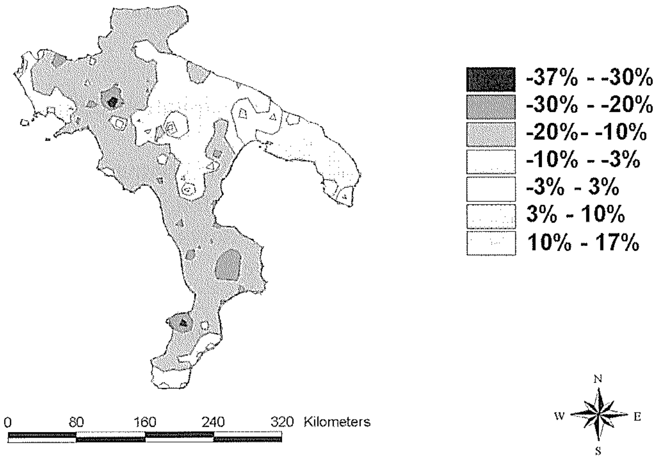

Fig. 4 Deviation of 1990s decade rainfall average from 1921–2001 average.

Only the southeastern part of the Apulia region, the Salentine Peninsula, shows a small positive deviation for the 1990s, due to heavy precipitation in 1995 and 1996. The most extreme deviation of the 10-year average from the MAP is –41.8%, but also the mean values for each region indicate the severity of the situation (Table 2). The results are worse if 2001 is included in the study because in many cases the amount of rainfall recorded this year was the historical minimum.

Table 2 Deviation of 10 years average from MAP.

Region	1981–1990	1991–2000
Apulia	–10.5 %	–3.8 %
Basilicata	–8.6 %	–7.6 %
Calabria	–12.1 %	–13.4 %
Campania	–11.4 %	–14.6 %

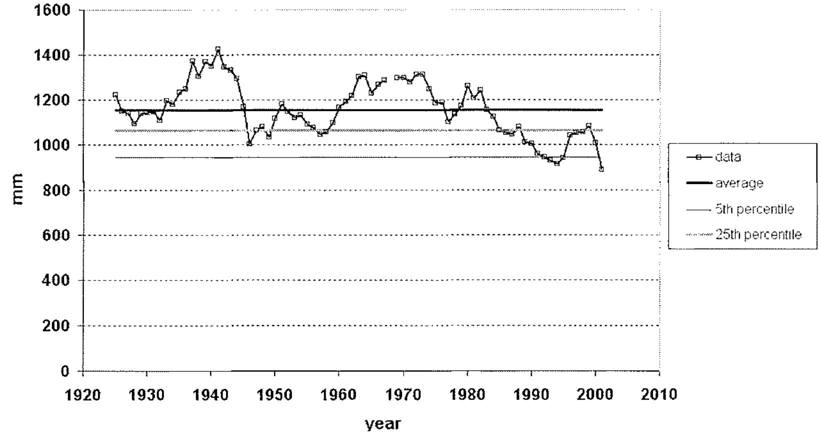

Fig. 5 Five-year moving averages of Campania region.

MOVING AVERAGE ANALYSES AND THE CHARACTERIZATION OF THE 2000–2001 DROUGHT

The ten-year average analysis shows the large precipitation deficit of the latest two decades.

However, a decade average is often the result of compensation between dry and rainy periods, generally occurring in shorter periods than 10 years. To investigate this aspect, moving averages on 2, 3 and 5-year windows have been calculated for the MSP. Figure 5 shows a plot of the moving averages.

The 2-year moving average indicates that the 2000–2001 drought is the most serious everywhere since 1921. Some dry periods in the 1940s and late 1920s are also evident in Apulia and Campania.

The 5-year average allows an evaluation of significant deviations from the average over longer periods. On this time scale, the years 1997–2001 appear to be the driest since 1921 in Campania. A dry period was recorded in Apulia from 1942 to 1950 (with the persistence of below average rainfall, even if this was without negative records for single years) and also from 1988 to 1992, which (with the period 1997–2001) was also the driest period in Basilicata and Calabria.

A remarkable result is that the 5-year average was continuously below the 1921–2001 average from 1978 in Basilicata and Calabria and from 1983 in Campania. This indicates that the last 20 years contributed strongly to the negative trends that occur over 96% of the area studied.

INCIDENCE OF 1981–2001 DATA IN DETERMINING THE NEGATIVE RAINFALL TREND

The rainfall variation in the last 20 years is now considered. Moving averages show that the negative present or recent trends have been particularly determined by a series of years with low rainfall amounts which occurred after 1980.

A Student's *t*-test has been conducted to assess if the time series 1921–1980 and 1981–2001 can be considered parts of the same population, for each gauge; i.e. the probability that average rainfall 1981–2001 was not significantly different from 1921–1980 average. Negative deviations are observed for 123 gauges out of the total of 126. A 5% significance level is found for 95 of the time series or gauges, a 1% significance level for 67 gauges. These amounts are higher than that found for MSP and are strongly indicative of an alteration in rainfall distribution in the last 20 years.

SEASONAL ANALYSIS

Analysis of trends has been also conducted on monthly data in order to investigate the seasonal contribution to negative trends and droughts. The most important contribution to the negative trend seems to be due to changes in winter precipitation (Fig. 6). The rainfall recorded for December to February (on average the most rainy period for the majority of the area studied), determines, as a regional average, more than 75% of the whole negative trend. The precipitation deficit of the last 20 years is then mostly due to the reduced contribution of winter rainfall. Spring (March–May) and autumn (September–November) also show negative trends, although these are much less evident. In many cases, autumn tends to become the wettest season, where large deficits were recorded during the last 20 years in winter precipitation. A positive trend was often found for summer events, due to the high intensity rainfalls recorded in recent years, in areas where summer rainfall is usually negligible.

Due to the arid character of summer in Southern Italy, the effect of the summer trend is negligible in terms of water resources availability. In any case, to evaluate the real impact of this rainfall trend on water resources, the effect of actual evapotranspiration variations cannot be neglected. Consequently the next objective was to characterise the trend of net rainfall (precipitation minus actual evapotranspiration), as determined by the simplest approach—a function of rainfall and temperature.

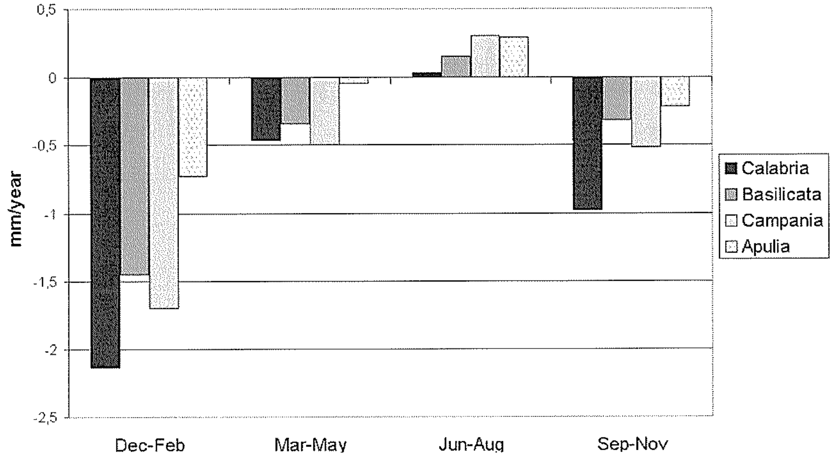

Fig. 6 Seasonal rainfall trend as mean for each region.

EXTENDING THE DATA SET TO THE 1829–1920 RAINFALL DATA

The situation before 1921 is characterized by the records from a few gauges, mostly installed after 1870, with the exceptions of Locorotondo (active since 1829) and the Capodimonte Observatory of Naples, (active from 1821 to 1969). Data from 13 gauges can be considered for Apulia, as a satisfactory statistic sample of "ancient" trends. Only four gauges recorded an almost complete time series in Campania; unfortunately the data base does not allow satisfactory conclusions for Basilicata and Calabria.

For gauges located in Apulia, data before 1920 indicate an average rainfall higher than the 1921–2001 average: this is consistent with the slightly decreasing trend observed in the MSP. The least squares lines of best fit for the 13 time series have similar gradients for the two periods (1880–2001 and 1921–2001) (Fig. 7). The decreasing trend observed over the latest 80 years seems to continue a process already started in 19th century, when average rainfall was higher than in the following period.

Data from the Locorotondo raingauge (Fig. 8) are the only series available for a period longer than 170 years and they show a decreasing trend of –2.1 mm year^{-1} for the whole period from 1829 to 2001. In particular, an annual rainfall of over 1000 mm was recorded 18 times between 1829 and 1920, and only 3 times after 1921. Of course data from only one gauge cannot be generalized, one factor is that the constancy of the method of measurement cannot be guaranteed over such a long period.

The "ancient" gauges located in Campania indicate differences. For two of four stations with continuous recording after 1880 there are decreasing trends only after 1920; the "ancient" trend is the opposite of the recent trend. The remaining gauges also show increasing trends for 1880–1920 but, in this case, they are consistent with the succeeding trend. These stations cannot be considered as representative of a generalized situation, since increasing trends for 1921–2001 are limited to but 4% of the study area.

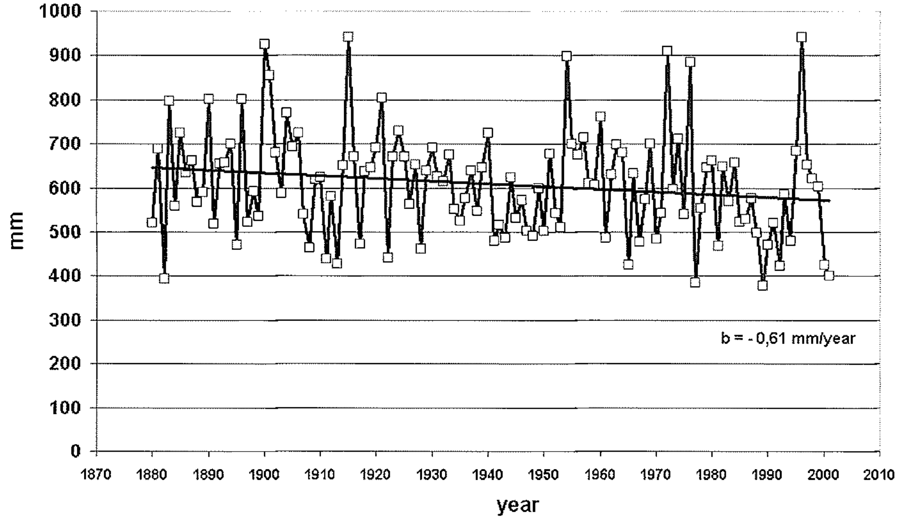

Fig. 7 Average rainfall and trend for Apulian raingauges since 1880.

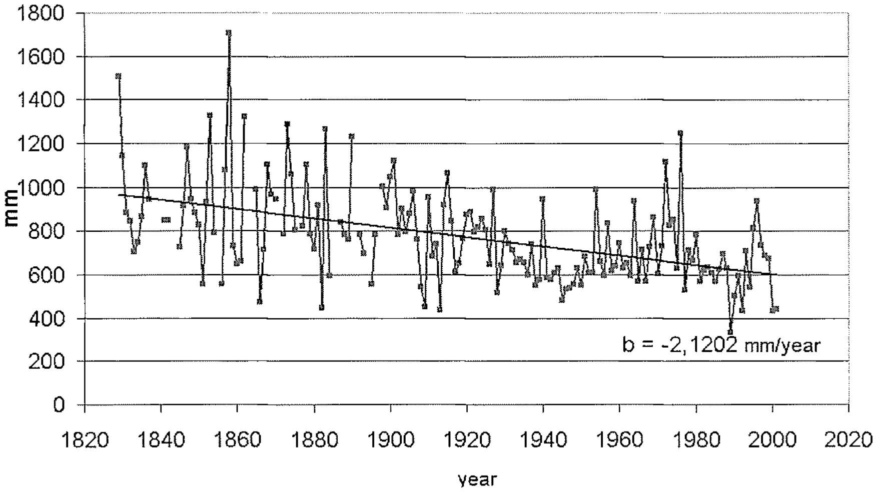

Fig. 8 Locorotondo raingauge: time series of annual rainfall 1829–2001 and trend.

This analysis, which excludes Calabria and Basilicata for which the data are insufficient, describes a situation which contrasts strongly with that for the Tyrrhenian and Adriatic areas. In the first case, a decreasing trend in rainfall is evident from 1980; in the second, a slight but almost continuous decreasing trend in rainfall is evident from 19th century.

TEMPERATURE (1924–2001) AND NET RAINFALL TREND

Monthly temperature series are available from 1924 for 22 of 126 gauges and the temperature trend for each gauge was determined. Although the highest temperatures have been recorded somewhere during the last ten years, this is not enough to assess a significant and generalized temperature trend over the whole period studied. However, temperatures higher than the average can cause a drought or, more probably, can enhance the effect of low rainfall periods. To evaluate if these effects exist or not, it is necessary to estimate evapotranspiration amounts.

The real or actual evapotranspiration E_r was calculated using Turc's formula (Turc, 1954):

$$E_r = P / \sqrt{0.9 + \left(P^2 / L^2\right)}$$

where P is the annual rainfall and L is given by:

$$L = 300 + 25T_p + 0.05T_p^3$$

in which T_p substitutes for T of Turc's formula and is calculated as a function of the rainfall and temperature regime (Castany, 1968):

$$T_p = \sum P_i T_i / P$$

where P_i, T_i ($i = 1, 2, \ldots 12$) are the monthly rainfall and temperature.

Table 3 Net rainfall trend and actual rainfall classes considering gauge data from 1924 to 2001. Mean Annual (actual) Precipitation Classes (MAPC, mm), Average Net Rainfall (ANR, mm), Net Rainfall Trend (NRT, mm year^{-1}), Net Rainfall Variation 1924 to 2001 (NRV) and ANR ratio (%).

MAPC	ANR	NRT	NRV/ANR
<600	85.5	–0.39	–33.1%
600–900	211.5	–1.01	–34.1%
900–1300	453.8	–2.25	–37.8%
>1300	962.1	–4.94	–39.6%

The inputs for these formulae were mean monthly data, according to the definition in Turc's method, but also the monthly data of each hydrological year. In this way a rough but simple estimate of the annual variation of evapotranspiration was obtained. The net annual rainfall was assessed as annual rainfall minus actual evapotranspiration.

The *Average Net Rainfall* (ANR) ranges from 52 to 1283 mm for the whole group of 22 gauges from 1924 to 2001; ANR is directly correlated to MAP. The *Net Rainfall Trend* is negative for the whole group and the gradient (NRT) worsens for an increasing MAP. The NRT ranges from –0.4 mm year^{-1} to –4.9 mm year^{-1} grouping these gauges by MAP (Table 3). Over the whole period the reduction of the net rainfall can be roughly assessed from 33 to 39 of the ANR percentage: this result is this reduction is higher or worse everywhere than the percentage calculated for the actual rainfall. This dramatic situation is due to two different phenomena. First of all the decreasing rainfall trend is more relevant during the winter months when the actual rainfall and net rainfall reach a maximum and actual evapotranspiration a minimum, as does temperature. Moreover the temperatures higher than the average recorded in the last ten years, often enhanced the effect of droughts.

CONCLUSIONS

The decreasing trend in rainfall has been generalized for the area considered for the period 1921–2001. This trend possesses a statistically high significance but it is not homogeneous and steady. Dramatic rainfall decreasing trends are observed along the Tyrrhenian coast between Basilicata and Calabria and in the central portion of Calabria on the Ionian side. The decreasing trend in Apulia is the lowest in absolute terms but is not less dramatic if normalized using the MAP for the region, the lowest in southern Italy. However, data of the last century suggest that the decreasing rainfall trend in Apulia, although less evident, is registered over a longer period, whereas in the other regions the sharp decreasing trends result from the last 20 years, characterized by a relevant rainfall deficit. The decrease in rainfall is higher where the MAP is higher, this is extremely dangerous for water supply as the main dams and aquifers utilized for this purposes are located in these areas. Moreover, the most important rainfall deficits are recorded in winter, usually the wettest season in the area studied. The increased occurrence of short-period intense precipitation in summer cannot balance these negative effects: in particular, if the effect of the temperature regime on evapotranspiration is considered.

The decreasing trend in net rainfall is worse everywhere than the rainfall trend. This dramatic situation is caused by two factors: the decreasing trend in rainfall is more relevant during winter months, and temperatures higher than the average have often enhanced the effects of droughts in recent years

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