Trend estimation of hydrological time series in Southern Italy

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Abstract
This paper shows some preliminary results obtained from trend detection analysis of rainfall data aggregated at different time scales. The rainfall measurements refer to a set of 26 rain gauges distributed in a typical catchment of Southern Italy. Particularly the analysis concerns the Mann-Kendall non-parametric test to detect trends of both monthly and annual rainfall time series in two overlapping time periods. Finally the procedure has also been used for trend detection of the annual maximum of hourly rainfall observed at Crati basin and over the whole Calabria region.

Key words Trend detection; non-parametric tests; rainfall time series

INTRODUCTION

Statistical analysis of climatic records for a convenient set of gauges can lead to the identification of some regularities in the non-stationary hydrological processes at basin scale, despite of the unpredictable fluctuation of the climatic variables (Demaree, 1990; Bardossy and Caspary, 1990). To this aim, several tests for detection of changes and shifts in hydrological time series can be usefully employed (Hirsch *et al*., 1982; Burn, 1994; Kiely *et al*., 1998; Kiely, 1999; Burn & Hag Elnur, 2002). Particularly non-parametric tests have the advantage to be distribution-free methods, suitable for non-normally distributed, censored and missing data (Hirsch *et al*., 1992; Salas, 1992).

This paper represents an initial step in research designed to detect some of the hydrologic impacts of climatic change for basins in Southern Italy. In this analysis some non-parametric tests for trend detection have been used to point out temporal and spatial behaviour of the cumulated rainfalls at annual and monthly time scales observed in the basin of Crati river (Calabria, Italy).

TREND DETECTION TESTS

The non-parametric tests adopted in this study are the Mann-Kendall (MK) test and Spearman's ρ (SR) test, which are rank-based methods for evaluating the presence of trends in time-series data, without specifying whether the trend is linear or non-linear. Both tests were found to be effective tools for identifying trends in hydrological and other related variables, resistant to the effect of extreme values, even if Spearman's ρ test is more rarely used in hydrological trend analysis (Hirsch *et al.*, 1982, 1992; Burn, 1994).

Table 1 Characteristic features of Mann-Kendall and Spearman's ρ tests.

TEST	Mann-Kendall	Spearman's ρ
Test statistic	$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\mathrm{sgn}(x_j-x_i)$	$D=1-\frac{6\sum_{i=1}^{n}[R(x_i)-i]^2}{n(n^2-1)}$
Mean	$E(S)=0$	$E(D)=0$
Variance	$\mathrm{Var}(S)=\left[n(n-1)(2n+5)-\sum_{i=1}^{n}t_i\,i(i-1)(2i+5)\right]/18$	$\mathrm{Var}(D)=\frac{1}{n-1}$
Standardized test statistic N(0,1)	$Z_{MK}=\begin{cases}\frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{for } S>0\\ 0 & \text{for } S=0\\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{for } S<0\end{cases}$ if N>10	$Z_{SR}=\frac{D}{\sqrt{V(D)}}$

The main characteristic features of both MK and SR tests are presented in tab.1. Among the various symbols of the formulae, x_i is the data value at time i, n is the length of the data set, sgn(z) is equal to +1, 0, -1 if z is greater than, equal to, or less than zero respectively, t_i denotes the number of tied values of extent i and $R(x_i)$ is the rank of i^{th} observation in the sample. Standardized test statistics Z_{MK} and Z_{SR} approximately follow a standard normal distribution (Kendall, 1962). The null hypothesis for both of the tests is that the data are independently identically distributed random variables, that is there is no existing trend in the data set. In the case of two-sided test, at the significance level of 0.05, if |Z..|>1.96 the existing trend is considered to be statistically significant.

RESULTS FROM TREND DETECTION ANALYSIS FOR RAINFALL DATA

Both MK and SR tests have been applied for trend analysis in rainfall time series recorded at 26 rain gauges of the Crati basin in Calabria (Italy), with more than 40 years of daily rainfall data (fig.1a). All the data series show a similar distribution of monthly rainfalls (fig.1b). The data was firstly analysed through regression analysis, that showed negative linear trends with time for most of the rain gauges (tab. 2). The result is confirmed by the Kendall's correlation coefficient τ, resistant to the effect of extreme values and to deviations from linear relationship. Yet the estimated values of both correlation coefficient and Kendall's τ indicate the low reliability of the resulting relationships.

Table 2 Sample statistics and correlation measures for linear trend of annual rainfall of Crati basin for 1920-00 period

Code	Elevation m)	Years	Mean (mm)	Slope regression	Kendall's τ
80	583	50	1116.5	-5.14	-0.26
90	534	66	953.2	-6.10	-0.37
000	710	60	1649.8	-5.07	-0.19
010	250	67	1011.1	-2.15	-0.16
020	620	47	1688.4	-12.79	-0.36
030	640	58	1006.6	-2.12	-0.20
040	482	68	1242.5	-6.55	-0.34
050	433	66	1020.9	+2.60	0.11
060	468	50	1350.3	-5.90	-0.18
070	870	50	1920.8	-29.42	-0.59
080	470	64	1645.2	+1.58	0.05
090	1291	42	1684.7	+2.57	0.07
110	1005	63	1148.5	+0.71	0.01
120	750	55	1057.9	-0.71	-0.03
130	97	58	877.7	-0.54	-0.03
140	203	47	817.7	+0.49	0.02
150	550	53	990.9	-4.35	-0.17
170	722	49	1235.4	-5.36	-0.20
180	353	71	873.3	-0.14	-0.04
190	369	63	852.2	-2.37	-0.24
200	440	60	1643.2	-2.30	-0.10
220	264	49	716.0	-17.17	-0.52
230	350	60	1749.8	-2.51	-0.09
240	767	54	1419.5	-6.80	-0.29
260	430	52	1339.6	+3.19	0.13
290	12	47	575.5	-3.50	-0.20

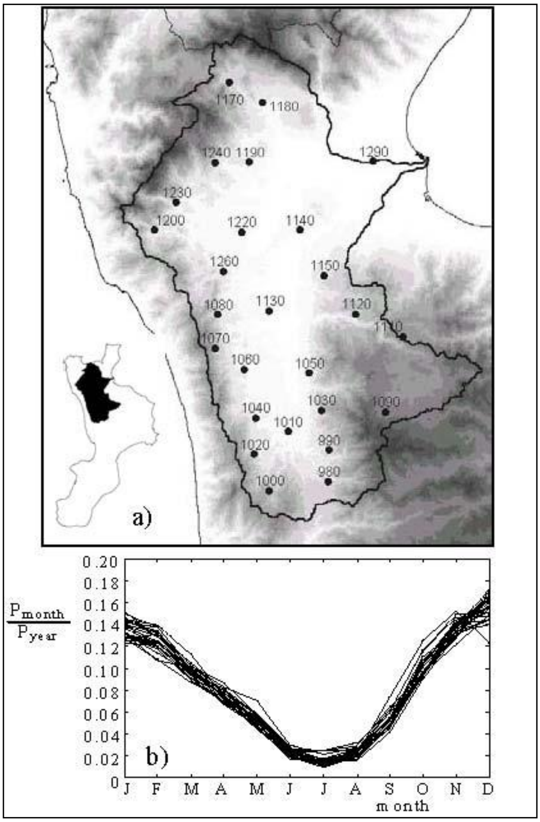

Fig. 1 a) Rain gauges of Crati basin.
b) Distribution of monthly rainfalls

The application of MK test for detecting trends in annual rainfalls has pointed out significant negative trends for about half of the rain gauges (tab. 3). Moreover a seasonal MK statistic for each rain gauge has been estimated, grouping all of the data by month and estimating a standardized variable through the sums of S statistic and variance calculated for each month (Hirsch *et al*., 1992). The comparison between the values of annual and seasonal standardized variables Z_{MK} shows similar results (tab. 3), though some monthly values of Z_{MK} can show high influence on the seasonal statistic (Hirsch *et al*., 1992). To explore changes in rainfall distribution throughout the year for different decades, trend analysis through MK test has been extended at basin scale for 13 hydrological variables (monthly and annual rainfalls) on two overlapping time periods, respectively 1920-2000 and 1960-2000 (tab. 4). The mean number of years per station of the two time periods is respectively 60.5 and 35.8.

Table 3 Trend detection from annual and seasonal estimation of MK statistic (In bold: statistically significant results).

Rain gauge	980	990	1000	1010	1020	1030	1040	1050	1060	1070	1080	1090	1110
Annual Z_{MK}	**-2.68**	**-4.35**	**-2.14**	-1.94	**-3.54**	**-2.16**	**-4.10**	1.30	-1.81	**-6.07**	0.55	0.61	0.08
Seasonal Z_{MK}	-1.89	**-4.49**	-1.45	**-2.74**	**-4.74**	-0.55	**-3.55**	**2.07**	0.77	**-7.83**	1.60	1.52	0.85
Rain gauge	1120	1130	1140	1150	1170	1180	1190	1200	1220	1230	1240	1260	1290
Annual Z_{MK}	-0.28	-0.35	0.16	-1.83	**-2.03**	-0.45	**-2.80**	-1.01	**-5.22**	-1.01	**-3.07**	1.38	**-2.00**
Seasonal Z_{MK}	**-2.51**	-0.50	1.84	-1.68	**-3.23**	0.40	**-2.12**	-0.23	**-9.88**	-0.63	**-2.53**	0.94	**-5.07**

At the annual time scale the number of rain gauges showing significant decreasing trends are practically the same in the two periods. For both the periods cumulated rainfalls in January appear to be significantly decreasing for more than 35% of the whole rain gauge set. Nevertheless variability in time for summer months is positive for the first period and mainly negative for the second one (tab. 4). Similar results were obtained from the application of Spearman's ρ (SR) test.

Table 4 Trend detection results for 26 rain gauges in two overlapping periods. (In bold: % > 0.20).

Rainfall	1920-2000			1960-2000		
	N° of trends ↓	N° of trends ↑	Significant results (%)	N° of trends ↓	N° of trends ↑	Significant results (%)
ANNUAL	12	0	**0.462**	13	0	**0.500**
January	8	1	**0.346**	11	0	**0.423**
February	4	0	0.154	3	0	0.115
March	1	0	0.038	3	0	0.115
April	1	0	0.038	5	0	0.192
May	8	0	**0.308**	2	0	0.077
June	3	0	0.115	7	0	**0.269**
July	0	5	0.192	6	0	**0.231**
August	3	7	**0.385**	3	1	0.154
September	1	0	0.038	3	0	0.115
October	3	0	0.115	2	0	0.077
November	3	0	0.115	0	0	0

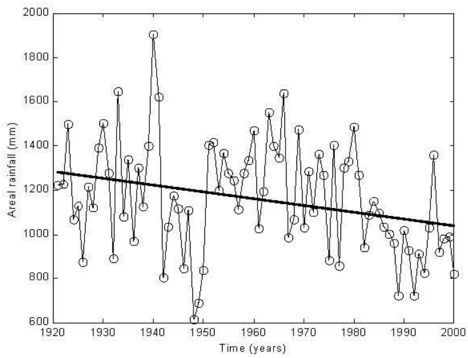

Fig. 2 Areal-average annual rainfalls for Crati basin.

Fig. 2 shows the areal-average annual precipitation for Crati basin during the 80-years study period. The decrease in annual precipitation over time is significant at the 5% level on the basis of the MK test (Z_{MK}=-2.72), though it has to be noticed that the spatial rainfalls in the period 1941-50 has been obtained from a few number of rain gauges. This trend is not consistent with the results of the trend analysis of both mean annual and monthly

temperature observed in two gauges within the basin (Ferrari & Terranova, *in press*), for which no significant trends were found for both the gauges.
Finally, as a preliminary study, an attempt was made to explore the links between trend occurrence of cumulated rainfalls and extreme rainfalls through MK test. To this aim, non-parametric analysis for 13 hourly rainfall series with more than 20 data observed in rain gauges of Crati basin (annual maximum of rainfalls with duration equal to 1, 3, 6, 12 and 24 hours) has shown significant decreasing trend in only one rain gauge (tab. 5). By extending analysis to 78 hourly rainfall series with more than 20 data distributed all over the region, about 15÷21 % of significant decreasing trends were detected. Decreasing trends become about 16÷29 % of the total when analysis is restricted to longer data series (38 hourly rainfall series with more than 40 data). In all the cases no significant increasing trends for the annual maximum of hourly rainfalls were detected.

Table 5 Trend detection results for the annual maximum of hourly rainfall series of Crati basin and of whole Calabria.

Duration of annual maxima of rainfall	Crati basin						Calabria region					
N° of rain gauges	1h	3h	6h	12h	24h		N° of rain gauges	1h	3h	6h	12h	24h
Significant negative trend in rain gauges with N≥**20** data	13	1	1	0	0	1	78	13	12	13	11	16
Significant negative trend in rain gauges with N≥**40** data	7	0	0	0	0	1	38	6	8	10	7	11

CONCLUSIONS

The statistical analyses performed for detecting trends in rainfalls observed in a basin of Southern Italy (Calabria) through Mann-Kendall and Spearman's ρ tests have shown significant decreasing trends in monthly and annual rainfalls for about half of the rain gauges. Little differences have been found between regional and at-site estimation of test statistics. The trend analysis repeated for two overlapping time periods has shown that 1960-2000 time span is characterised by a greater number of rain gauges with negative trend in winter months and a lower number of rain gauges with positive trend in summer months than the 1920-2000 time period. Similar results arise for detection of significant trends in cumulated annual rainfalls of the two periods. As a conclusion, though some preliminary results have been presented here, in future works an attempt to establish a linkage between climatic change and the observed hydrological variables will be made, with further analyses performed on a greater number of climatic and meteorological variables.

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