Investigating the changes in extreme rainfall series recorded in an urbanised area

G. Aronica*, M. Cannarozzo and L. Noto****

*Dipartimento di Costruzioni e Tecnologie Avanzate, Università di Messina , Salita Sperone 31, S. Agata – 98166 Messina, Italy

**Dipartimento di Ingegneria Idraulica e Applicazioni Ambientali, Università di Palermo, Viale delle Scienze – Parco d'Orleans, 90128 Palermo, Italy

Abstract The aim of this study is to investigate and quantify changes in the rainfall regime of the metropolitan area of Palermo characterised by increasingly strong urbanisation. The rainfall data, considered in this study, were collected on a yearly basis from eight rain gauges within and outside the metropolitan area of Palermo, Sicily, Italy. A preliminary analysis made on the annual total rainfall depths showed a global reduction of total annual rainfall, with two different trends: more regular for the series observed in the rain gauges within the urbanised area and more variable for the series observed in the rain gauges outside the area. A further analysis has been performed using the series of maximum intensity for fixed duration (1, 3, 6, 12, 24 hrs) and annual daily maxima. The analysis of the trend in the extreme rainfall series has been performed by estimating the maximum rainfall depth corresponding to a fixed return period using the EV1 distribution with parameters estimated using *L*-moments. The analysis of all series indicates a global reduction of rainfall intensities, both for internal and external series, in disagreement with the results obtained by other authors.

Keywords Extreme rainfall; extreme value distribution; time-series; urban hydrology

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Introduction

In recent decades many natural areas have been subjected to an increasing urbanisation with possible consequences on their hydrological behaviour. These changes could have an affect on local rainfall characteristics. Many authors (De Michele *et al.*, 1998; Pagliara *et al.*, 1998; Brath *et al.*, 1999; Kamaguchi *et al.*, 1999) have claimed the presence of a valuable increasing tendency in high intensity rainfall in urban areas. For urban drainage systems, these changes can have a strong impact because they have small basin areas and flood arrival times are generally short.

De Michele *et al.* (1998) have estimated critical design storms, using 90 years of continuous data collected in four northern Italian cities and fitting the annual maxima from historical records, thus assessing the progress of the design storm in time. The results show the presence of a significant increasing trend in the critical design storm, starting in the years around 1940. Furthermore the estimation of the critical design storm using all the data shows that the longer are the sample sizes of historical data, the lower is the bias in the critical design storm induced by non-stationarity.

Pagliara *et al.* (1998) applied Kendall's test to the extreme series at some gauges in Tuscany, Italy, in order to detect a definite increasing or decreasing trend. The results have shown a clearly increasing trend for the shortest duration but no trend for longer duration.

Kamaguchi *et al.* (1999) analysed the rainfall records of a Yokohama local weather station in order to investigate trends in short-term rainfall. These analyses showed that the number of short duration rainfalls and the average of unit time intensity and 5-minute intensity was increasing. Furthermore the probable rainfall intensity estimated from recent data was higher than that from the data of the previous 20 years.

The aim of this study is to investigate and quantify changes in the rainfall regime of the metropolitan area of Palermo characterised by a strong urbanisation, which in a few decades has completely modified its natural environment.

The rainfall data

The rainfall data considered in this study were collected on a yearly basis from eight rain gauges within and outside the metropolitan area of Palermo. The location of the rain gauges is showed in Figure 1 and their main characteristics as N_d (sample size of daily annual maxima), μ_d (average of daily annual maxima), $_d$ (standard deviation of daily annual maxima), N_y (sample size of annual total rainfall depth), $_y$, (average of annual total rainfall depth), $_y$ (standard deviation of annual total rainfall depth) and N_m (sample size of annual maxima for fixed duration), are given in Table 1.

A preliminary analysis has been made on the annual total rainfalls. In Figure 2 the 10 years moving averages of the total annual rainfall from the eight rain gauges are shown. Although the rain gauges are mutually close (Figure 1), there are significant differences in the averages and in the trend. Particularly, the rain gauges within the metropolitan area show smaller values in comparison with the values for the rain gauges outside the area. Also there are differences in the trends of total annual rainfall, which is more regular for the series from the rain gauges within the urbanised area, more variable for the series from the

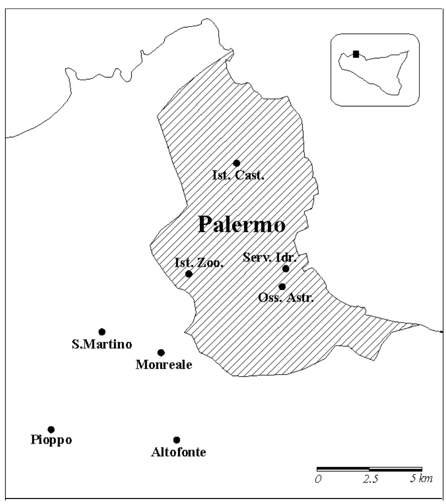

Figure 1 Location of rain gauges

Table 1 Characteristics of the rainfall series

Rain gauge	Altitude (m)	N_d	μ_d (mm)	$_d$ (mm)	N_y	μ_y (mm)	$_y$ (mm)	N_m
Altofonte (EXT)	354	60	73.9	42.6	68	939.3	245.5	41
Monreale(EXT)	310	55	68.9	29.6	39	881.2	175.3	39
Pioppo (EXT)	495	60	88.6	51.7	65	1212.8	277.5	44
S. Martino(EXT)	570	68	73.7	31.4	69	1026.6	242.8	46
Ist. Castelnuovo (INT)	54	54	60.4	22.4	38	678.4	128.4	39
Ist. Zootecnico (INT)	113	62	68.2	38.4	65	857.4	199.4	33
Serv. Idrografico (INT)	19	74	62.3	37.1	72	622.9	151.1	45
Oss. Astronomico (INT)	31	76	55.6	28.7	73	559.7	228.1	40

Table 2 Characteristic of the two clustered series

Series	N_d	μ_d	d	N_m
		(mm)	(mm)	
Internal	80	60.5	25.5	55
External	77	76.8	35.9	62

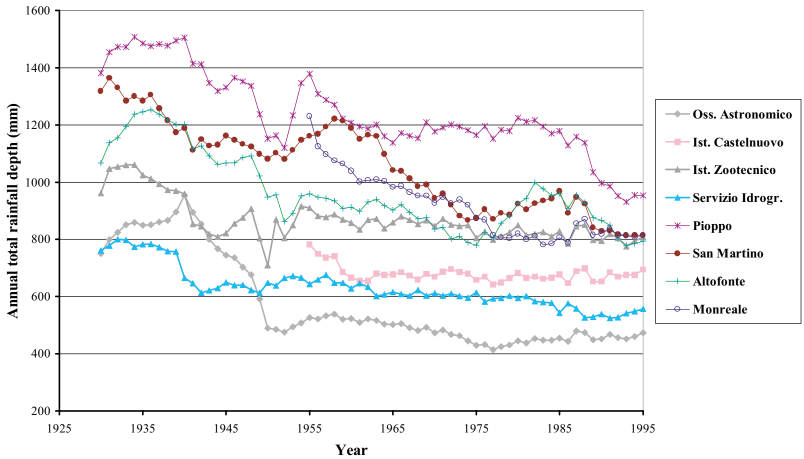

Figure 2 10-years moving averages total annual rainfall series

rain gauges outside the area. Now, while the difference in the total annual rainfall is due to orographic effects as the external stations are located at higher altitude (Table 1), the differences in the trend are worth investigating.

Following Montanari *et al.* (1996), who found a decreasing trend together with an increase in precipitation intensity by analysing the rainfall records observed in some cities of Northern and Central Italy, a further analysis has been performed using the series of maximum intensity for fixed duration (1, 3, 6, 12, 24 hrs) and annual maximum daily series.

Rainfall series analysis

The analysis of the trend in the extreme rainfall series was made by estimating the maximum rainfall depth corresponding to a fixed return period for the distribution historical rainfall depths as proposed by De Michele *et al.* (1998). Firstly, following the information derived from the analysis of characteristics of rainfall series (Figure 2 and Table 1) and on the basis of rain gauge locations (Figure 1), the eight rainfall series have been clustered into two main series by averaging the values of single rainfall series (Table 2).

The estimation of the quantiles was carried out, for a return period of 10 years, on the two clustered series using two different approaches. In detail, the estimation of maximum rainfall has been carried out for each year of the observation period starting from the 20th year. Approach #1 is made by fitting only the historical annual maximum rainfalls of the past 20 years, while Approach #2 is made by fitting the historical annual maximum rainfalls using all the past observations.

The rainfall data were fitted using the GUMBEL (EV1) distribution:

$$P(x) = \exp \; -\exp \; -\frac{(x- \quad)}{\quad} \qquad (1)$$

where and are the scale and location parameters. In particular, the parameter represents the mode of the distribution and consequently depends on the mean and the variance of the variable x, while parameter only depends on the variance of x. Parameter estimation was made using L-moments methods (Hosking, 1990) because they are less prone to adverse sampling effects than conventional moments (Kottegoda and Rosso, 1998). The expressions that link coefficient and to L-moments are the following:

$$= \frac{L_2}{\ln 2} \quad (2)$$

$$= L_1 - 0.5772 \Diamond \quad (3)$$

in which L_1 and L_2 are the L-moments of first and second order.

Description of results

The results of the estimation of the 10-years quantiles, for 1-hour duration, are reported in Figure 3 (approach #1) and in Figure 4 (approach #2). These figures show a different behaviour between internal and external series. Particularly, in Figure 3 it can be observed that the external series shows a trend more regular than internal ones (for 10-years quantiles, $CV_{internal}$=0.143 – $CV_{external}$=0.064). It's worth pointing out a particular trend of quantiles: external series present higher values than internal series, but this trend clearly changes from 1966. This behaviour, in disagreement with the total annual rainfall (Figure 2), is confirmed by the trend of quantiles in Figure 4 in which a strong reduction of 10-years quantiles can be observed only for internal stations, while 10-years quantiles relative to external stations remain substantially unchanged.

A slightly different behaviour can be noticed in Figure 5 and Figure 6 where the 10-years quantiles, for 6-hour duration, are reported (approach #1 and approach #2).

Figure 7 shows the estimated 10-year quantiles for 24-hour duration. These series indicate a reduction of the quantiles, with higher values for the external series than for the internal series. Figure 8, which shows the trend in 10-year quantiles estimated using the approach #2, confirms the previous results, showing values of the external quantiles higher than for internal quantiles.

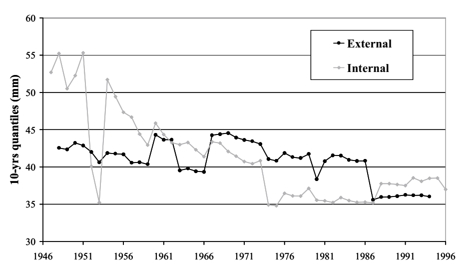

Figure 3 Approach #1 – 1-hr duration

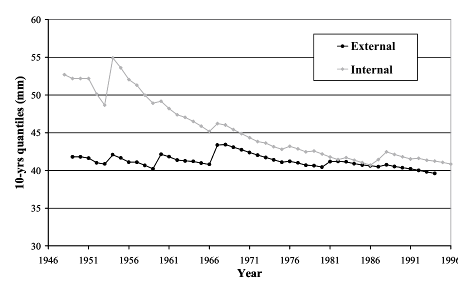

Figure 4 Approach #2 – 1-hr duration

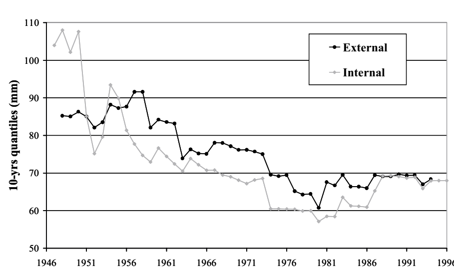

Figure 5 Approach #1 – 6-hr duration

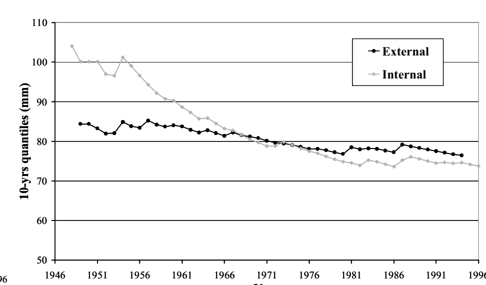

Figure 6 Approach #2 – 6-hr duration

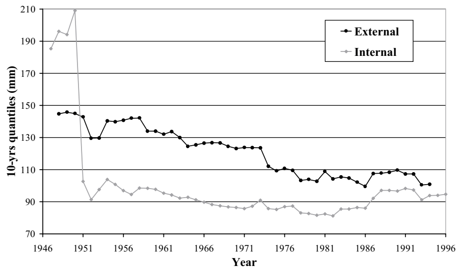

Figure 7 Approach #1 – 24-hr duration

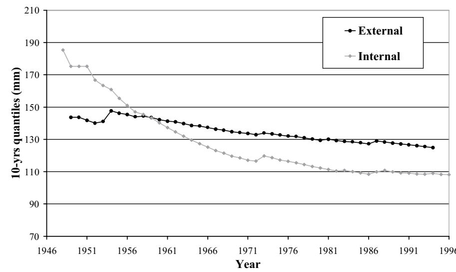

Figure 8 Approach #2 – 24-hr duration

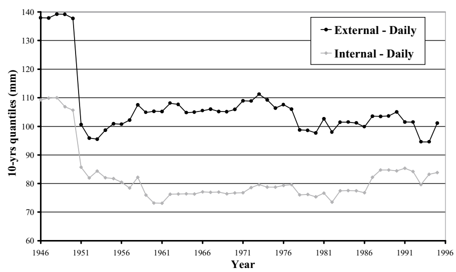

Figure 9 Approach #1 – Daily maxima

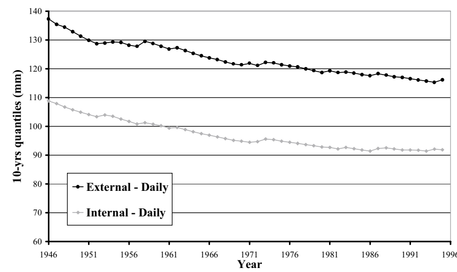

Figure 10 Approach #2 – Daily maxima

Table 3 Maximum variation of 10-year quantiles

	Approach #1		Approach #2	
Duration (hr)	Internal	External	Internal	External
1	37%	20%	26%	9%
6	47%	34%	29%	10%
24	62%	32%	42%	15%

The sharp reduction of the quantiles found for 24-hour duration, is less evident if the duration decreases. This behaviour can be due to the presence of outliers, detected using the methodology proposed by the Water Resources Council (1971), for the catastrophic rainfall event of 1931, in particular.

Finally, the analysis of all series shows a global reduction of rainfall intensities both for internal and external series in clear disagreement with the results obtained by other authors (De Michele *et al.*, 1998; Pagliara *et al.*, 1998; Kamaguchi *et al.*, 1999). This reduction seems to be linked to the heavy rainfall occurrences of the early 1930s. Under these circumstances, the estimation of quantiles is highly affected by these extreme events, with high variability as a consequence (Table 3).

From Table 3, it can be observed that, both for approach #1 and approach #2 and for increasing duration, the quantiles of the external series have less variation in comparison with the quantiles of the internal series. Furthermore, by comparing Figure 3, Figure 5 and Figure 7, one sees that for decreasing durations the curves become less and less distinct with the consequence that extreme rainfalls are not sensitive to the location of rain gauges.

In order to point out the results obtained, the same analysis has been performed on the annual maximum daily rainfall with a larger sample size (Table 2). Also in this case, a decreasing trend has been found with a clear distinction between internal and external series (Figure 9 and Figure 10) using approach #2. The difference in the trend between the annual maximum daily series and the 24-hour duration series (Figure 7 and Figure 8) is surely due to the 1931 rainfall event, which is an outlier only for the fixed duration series (12-hr and 24-hr) and not for the daily maxima.

Conclusions

A study has been made to investigate and quantify changes in the rainfall regime of the metropolitan area of Palermo characterised by a strong urbanisation.

A preliminary analysis of the total annual rainfall depths highlighted a global reduction in precipitation. This reduction is characterised by two different trends: more regular for the series observed in the rain gauges within the urbanised area, and more variable for the series observed in the rain gauges outside the area. A further analysis has been made using the series of maximum intensity for fixed duration (1, 3, 6, 12, 24 hrs) and annual daily maxima by estimating the maximum rainfall depth corresponding to a fixed return period using the EV1 distribution. The examination of the 10-yr quantiles indicates a global reduction of rainfall intensities, both for internal and external series, in disagreement with the results obtained by other authors. Furthermore, the external series show a more regular trend or sometimes a slight decrease. The internal series, however, show a higher variability and a more significantly decreasing trend.

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