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EXTREME RAINFALL IN COASTAL METROPOLITAN AREAS OF CENTRAL ITALY: ROME AND PESCARA CASE STUDIES

ABSTRACT: BRAMATI M.C., TARRAGONI C., DAVOLI L. & RAFFI R., *Extreme rainfall in coastal metropolitan areas of Central Italy: Rome and Pescara case studies.* (IT ISSN 0391-9838, 2014).

This study analyzes the historical series of precipitation fallen along Latian coast and Abruzzo coast, and extreme rainfall in the context of climate change. Daily precipitation data cover the years ranging from 1922 to 2009 for one meteorological station, and from 1951 to 2010 for five stations. We focus on the extreme values following two approaches: the first one is based on the maximum annual daily rainfall series (1-day, 2-day and 3-day) for which suitable probability distributions are fitted. The second one is based on the series of peaks over annual thresholds (POT) for which the best fitting distribution is identified. The aim of this analysis is to estimate rainfall return levels for various return periods. This is particularly helpful to the Local Administration for the urban planning and for alerting residents in metropolitan areas.

KEY WORDS: Extreme rainfall, Homogeneity test, Return level, Long-Term climatic time series, Metropolitan area.

RIASSUNTO: BRAMATI M.C., TARRAGONI C., DAVOLI L. & RAFFI R., *Piogge intense in aree costiere metropolitane dell'Italia centrale: i casi di studio di Roma e Pescara.* (IT ISSN 0391-9838, 2014).

Nel presente lavoro sono state analizzate serie storiche di precipitazione verificatesi lungo la costa del Lazio e dell'Abruzzo e valutate le precipitazioni intense, alla luce dei cambiamenti climatici in atto. I dati giornalieri sono relativi ad un intervallo compreso tra il 1922 e il 2009 per la stazione del Collegio Romano (Roma) e tra il 1951 e il 2010 per altre cinque stazioni meteorologiche (Civitavecchia, Ostia, Ardea, Pescara, Ortona). Le indagini hanno riguardato i valori estremi di precipitazione articolati secondo due metodologie. Il primo metodo è basato sulla serie delle piogge giornaliere massime annuali di durata da uno a tre giorni consecutivi. Il secondo metodo è basato sulla serie dei valori che superano il limite annuale del 95° percentile. Scopo del lavoro è stato quello di verificare la presenza di un *trend* delle piogge intense, di stimarne i tempi di ritorno a breve e medio termine, di stimare la diversa intensità delle piogge sulle aree metropolitane di Roma e Pescara e di fornire un utile strumento di allerta e pianificazione per le amministrazioni locali.

PAROLE CHIAVE: Piogge intense, Test di omogeneità, Tempi di ritorno, Serie climatiche di lungo periodo, Area metropolitana.

1. INTRODUCTION

The relationship between extreme rainfall, climate changes and the damaging effects that such events can produce, is a problem not yet completely clarified by scientists. Societal impacts from weather and climate extremes, and trends in those impacts are a function of both climate and society (Chagnon & *alii*, 2000). In particular damages induced by floods and the increase in damage is strongly associated with the increased of heavy precipitation, population and wealth (Peterson & *alii*, 1998).

Other studies have concluded that over many large regions (eastern parts of north and south America, northern Europe, northern and central Asia), precipitation increased significantly. Drought has been evidenced in Sahel, the Mediterranean basin, southern Africa, and parts of southern Asia (Hess & *alii*, 1995; Regione Lazio, 2011; Hamilton & *alii*, 2001; Boyles & Raman, 2003; Liu & *alii*, 2009; Lebel & Ali, 2009).

The Mediterranean area is on the whole not particularly rainy with semi-arid southern parts. It is dominated by a regular aridity during summer and recurrent periods of drought or extreme precipitation during the rainy season (Droguedroit & Norrant, 2003). Several studies have contributed to the analysis of precipitation variability over the Mediterranean basin. Results from these studies show a precipitation decrease, not always significant, or the lack of linear trend (Brunetti & *alii*, 2006; Gonzales & *alii*, 2011). In particular, precipitation decrease is evident dur-

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ing the winter season in large part of the eastern Mediterranean area (Pielke & Downton, 2000), over Greece (Sharma & *alii*, 2000; Feidas & *alii*, 2007) and along the Mediterranean coast of Turkey (Kadioglou, 2000).

The Italian climate is becoming warmer and drier due to a reduction in both annual precipitation and wet days (D'Alessandro & *alii*, 2002; Brunetti & *alii*, 2006). Indeed, the number of wet days in the year has a clear and highly significant negative trend all over Italy (Brunetti & *alii*, 2004). This depends mainly on the winter season, which accounts for about the 50% of decrease in the number of wet days in northern Italy, and about the 75% decrease in southern Italy. Recently, it has been shown that such a negative trend is more pronounced in the last decade and total precipitation has significantly decrease in central and southern Italy (Brunetti & *alii*, 2012). Some studies carried out on daily rainfall data (IPCC, 1996; IPCC, 2013) show the presence of a positive trend in the average rainfall per wet days for some areas, and a tendency toward higher frequencies of heavy and extreme rainfalls in the last decades. The main areas where significant positive trends have been observed are the USA (Karl & *alii*, 1995; Karl & Knight, 1998; Trenberth, 1998; Kunkel & *alii*, 1999), Japan (Iwashima & Yamamoto, 1993), eastern and northeastern Australia (Suppiah & Hennessey, 1998; Plummer & *alii*, 1999), South Africa (Mason & *alii*, 1999), the UK (Osborn & *alii*, 2000) and northern Italy (Brunetti & *alii*, 2000). Also, the results of Førland & *alii* (1998), that found an upward trend over northern Europe in annual maximum 1-day precipitation in the present century, confirm this tendency.

This paper is about a statistical analyses of historical series of precipitation fallen along Latian and Abruzzo coasts. The aim of this study is to test for the presence of trends, to estimate the return levels of extreme rainfall for various return periods, and to check whether differences in the magnitude of extreme rainfalls exist between central Tyrrhenian and Adriatic coasts.

The paper is organized as follows: Section 2 contains the description of data used and the statistical methodology, Section 3 briefly recalls the main physiographic and climatic features of the areas under study, whereas Section 4 reports the main results of the analysis. In Section 5 the main conclusions of the study are drawn.

2. DATA AND METHODOLOGY

2.1 Data

Temperature data are obtained from four meteorological stations: Pescara and Ortona stations for the Adriatic side and Civitavecchia and Ardea stations for the Tyrrhenian side. Data sources are the Hydrological Annals available in the web site of Regione Abruzzo(http://www.regione.abruzzo.it/xIdrografico/index.asp) and other meteorological information sources (Meteographic Information System of Regione Lazio, http://www.idrografico.roma.it/asp.net/default_ok.aspx). Data refer to the mean of daily temperature calculated as half-sum of minimum and maximum temperature observed, and cover several years as displayed in tab. 1.

TABLE 1 - Temperature data (in bracket number of missing months)

Metropolitan region	**Station Name**	**Recording period**	**Missing data year (month)**
Lazio	Civitavecchia (21 m a.s.l.)	1959 - 2009	2001 (1) - 2000 (1) - 1998 (4) - 1997 (12) - 1991 (1) - 1985 (1)
	Ardea (47 m a.s.l.)	1951 - 2009	2001 (1) - 1999 (2) - 1996 (3) - 1994 (1) - 1992 (3) - 1983 (12) - 1981 (1) - 1977 (1) - 1974 (1) - 1968 (12) - 1965 (12) - 1964 (12) - 1963 (12) - 1962 (12) - 1961 (1) - 1959 (1) - 1958 (12) - 1956 (12)
Abruzzo	Pescara (2 m a.s.l.)	1975 - 2009	1978 (12)
	Ortona (68 m a.s.l.)	1976 - 2009	–

Daily rainfall data are collected from six rain gauge stations: Pescara and Ortona stations for the Adriatic side and Civitavecchia, Roma Collegio Romano, Ostia and Ardea stations for the Tyrrhenian side. Rainfall data sources are the same as those for thermometric data. Rainfall data from the Hydrologic Annals refer to a 24-hour-cycle, starting from 9.00 of the preceding day to 9.00 of the day referenced (Pescara and Ortona's stations). Data from the Meteographic Information System (Civitavecchia, Roma Collegio Romano, Ostia and Ardea stations) use a 0.00-24.00 day.

Rainfall records are daily and cover years 1951-2010, except for Rome CR site for which data are available from 1922 to 2010. The detailed longitudes, latitudes, heights above sea level and measurement periods are provided in tab. 2, whereas site locations are displayed in fig. 2 and fig. 3 below.

TABLE 2 - Rain gauging stations

Metropolitan region	**Station Name**	**Recording period**	**Latitude N**	**Longitude E**
Lazio	Roma CR (63 m a.s.l.)	1922 - 2010	41°53'56"	12°28'51"
	Civitavecchia (21 m a.s.l.)	1951 - 2009	42°05'40"	11°47'02"
	Ostia - Idrovore (5 m a.s.l.)	1951 - 2009	41°44'46"	12°19'07"
	Ardea (47 m a.s.l.)	1951 - 2009	41°36'41"	12°32'20"
Abruzzo	Pescara (2 m a.s.l.)	1951 - 2010	42°27'36"	14°13'16"
	Ortona (68 m a.s.l.)	1951 - 2010	42°21'40"	14°24'00"

The analysis is carried out on daily rainfall records, where rainy days are defined as days with at least 1 mm of rain. The total amount of analyzed data consists of 137179 records.

Given the use of several sources, data quality might be a serious concern. This is also due to possible changes in the technology of gauging instruments used through time. For these reasons, a first quality check is done by means of some preliminary statistical tests. Hypothesis testing concerns the homogeneity and randomness of data as well as the presence of trend, either deterministic or stochastic. Missing observations are in almost all series at different time periods, sometimes covering a whole year. No treatments are undertaken to correct for them. In particular, for the Rome CR series, which covers the longest time range, records are missing for several years before 1950 (i.e. years 1928, 1934, 1937, 1941, 1949), therefore the analysis is restricted to the range 1951-2010, also for a matter of comparability with the other rain gauging stations. Some descriptive statistics on the data analysed are displayed in tab. 3.

TABLE 3 - Descriptive indicators of the daily data over the years 1951-2010

Metropolitan region	Station Name	Recording period	Latitude N	Longitude E
Lazio	Roma CR (63 m a.s.l.)	1922 - 2010	41°53’56”	12°28’51”
	Civitavecchia (21 m a.s.l.)	1951 - 2009	42°05’40”	11°47’02”
	Ostia - Idrovore (5 m a.s.l.)	1951 - 2009	41°44’46”	12°19’07”
	Ardea (47 m a.s.l.)	1951 - 2009	41°36’41”	12°32’20”
Abruzzo	Pescara (2 m a.s.l.)	1951 - 2010	42°27’36”	14°13’16”
	Ortona (68 m a.s.l.)	1951 - 2010	42°21’40”	14°24’00”

2.2 Methodology

Besides data availability, data quality is of fundamental importance for an accurate climate change analysis. The climate data used must be homogeneous. A homogeneous climate time series is defined as one where variations are caused only by variations in weather and climate. Unfortunately, most long-term climatic time series have been affected by a number of non-climatic factors that make these data unrepresentative of the actual climate variation occurring over time. These factors include changes in: instruments, observing practices, station locations, formula used to calculate means, and station environment. Homogeneity testing and the adjustment of climatic time series for no-climatic variations are an essential tool for any climate change analysis (Liu & *alii*, 2008). Therefore, the data analysis carried out in this work follows three steps. First, we test for the homogeneity of the rainfall data, applying the Q and R Buishand (1982)’s test statistics.

Also, we check for the presence of deterministic and/or stochastic trends in the data by means of correlation tests (assuming a linear trend) and tests for stationarity (Dickey & Fuller, 1979).

In the second step we estimate the return levels using the statistical analysis of extremes. We fit several distributions on annual rainfall maxima and we compare the resulting return levels to the ones obtained with the Peak Over Thresholds (POT) analysis. Given that the annual maxima analysis ignores much of the data, it is often more useful to look at the exceedances over a given threshold instead of simply the maximum of the data. This second approach consists of fitting the exceedances to a Generalized Pareto Distribution (GPD) for a selected threshold and it is generally known as POT or partial-duration analysis. To study extreme values with the POT approach using a GPD, it is first necessary to select the threshold u.

Threshold selection is an important issue, and still an area of active research. It is desired to find a threshold that is high enough that the underlying theoretical development is valid, but low enough that there is a sufficient data with which to make an accurate fit. That is, selection of a threshold that is too low will give biased parameter estimates, but a threshold that is too high will result in large variance of the parameter estimates. Therefore, some *descriptive* tools for the threshold selection are used, specifically the mean residual life plot, also referred to as mean excess plot and another method involving the fitting of data several times to a GPD using a range of different thresholds. In the POT analysis we consider as days with extreme precipitation those with daily precipitation amount exceeding the 95th percentile of the precipitation on rainy days (Chu & *alii*, 2010; Gao & *alii*, 2013). Thus, we consider the distribution of the 95th percentile excess rainfall instead of the annual maxima, assuming that parameters of the fitted distributions do not vary in time.

In the last part of the analysis we drop this assumption and we test for parameter variation considering a linear trend for the threshold and a cyclically varying scale.

3. GEOGRAPHIC SETTING

3.1 Physiographic and climatic features of the Latian coast

The considered coast stretches for about 150 km, with a general NW-SE trend, from Marta River to Nettuno (fig. 1). The Tiber River delta characterizes its central part, forms the main sedimentary input and mainly determinates the sedimentary dynamics of the whole area.

Streams debouching along the considered Tyrrhenian coast may be divided into three different types:

i) rivers with basin extension > 10,000 km^2 mostly falling outside the metropolitan area,
ii) rivers with basin ranging from 100 to 1,000 km^2 partly falling inside the metropolitan area,
iii) rivers with basin extension mostly lower than 100 km^2 and mostly falling inside the metropolitan area.

To the first type belongs only the Tiber River which in part is fed by waters held in the Apennine lime-stones and in part by waters coming from reliefs of the Tyrrhenian border and mostly made by Plio-pleistocene terrigenous sediments. To the second type belong rivers located north of the Tiber mouth (fig. 1). They flow on the western slope of volcanic reliefs. Streams belonging to the third type drain the eastern slopes of the Latian volcanic edifices.

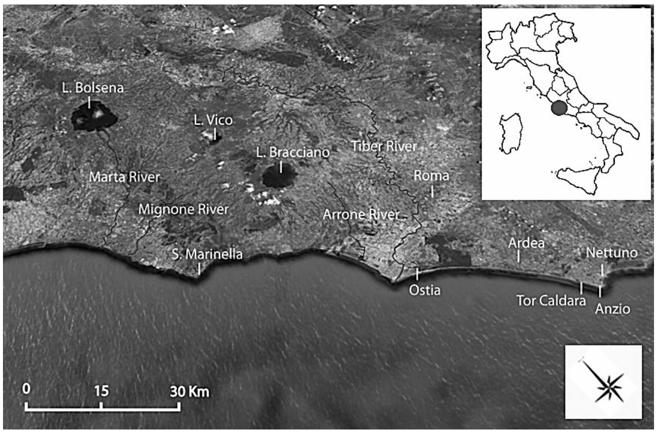

FIG. 1 - Location map of the Tyrrhenian coast *(from Google Earth)*.

According to the Köppen Climate System, the climate of the considered Tyrrhenian coastal sector falls within the humid mesothermal climates (C), Mediterranean type with very hot dry summer (Csa). It is characterized by the presence of the subtropical anticyclone during summer and by precipitation prevailing in winter, due to Westerlies and to low pressures dominating this season. Summer is warm and dry, followed by mild and humid autumn and winter. The mean annual temperature (tab. 4), calculated for the 1951-2009 period at the Civitavecchia, Roma - Collegio Romano (Rome CR) and Ardea stations, is 16.7 °C that of the hottest month (August) 24.8 °C and the one of the coldest month (January) is 9.6 °C. The mean annual and monthly minimum and maximum temperatures are reported in tab. 4.

TABLE 4 - Average climatic characteristics Lazio coast (Tyrrhenian side)

Month	Mean temperature (°C) Min	Max	Mean	Mean rainfall (mm)	Rainy Days
Jan	6.9	12.7	9.6	74.2	7.9
Feb	7.0	13.3	10.0	66.9	7.6
Mar	8.6	15.0	12.0	56.6	7.1
Apr	11.1	17.5	14.2	56.3	7.0
May	14.9	21.6	18.2	39.9	4.8
Jun	18.5	25.2	21.7	23.6	3.1
Jul	21.4	28.0	24.5	12.9	1.4
Aug	21.7	28.0	24.8	25.9	2.2
Sep	18.9	25.5	22.0	69.8	5.8
Oct	15.5	21.8	18.5	101.7	7.2
Nov	11.4	17.4	14.2	110.2	9.3
Dec	8.1	13.9	10.9	89.5	9.1
Annual	**13.7**	**20.0**	**16.7**	**727.5**	**72.5**

Mean annual rainfall is 727.5 mm. Autumn is the most humid season and November is the wettest month with 110.2 mm average rainfall. Summer is the driest season and arid month with July 12.9 mm average rainfall.

The absolute highest daily precipitation recorded in the study period is 198 mm on October 27, 1953, at Ostia station.

Physiographic and climatic features of the Abruzzo coast

The study area extends for about 35 km with a general NW-SE trend from Città Sant'Angelo-Montesilvano to Ortona (fig. 2). The coast is mainly made by beaches and partially by cliffs. Streams having their mouth along the Adriatic coast of the Pescara-Ortona metropolitan area, may be classified in two types:

i) streams with fluvial basin extending over more than 1,000 km^2 partly fed by Meso cenozoic carbonatic reservoirs of central Apennines;
ii) streams with basin generally ranging from 100 to 1,000 km^2 in size.

For the streams of the first type lithology of the basin is made in the upper part by carbonatic-siliceous sequences and in the middle and lower parts, prevailingly by arenaceous-clayey and locally conglomeratic sequences (Pescara River) (fig. 2).

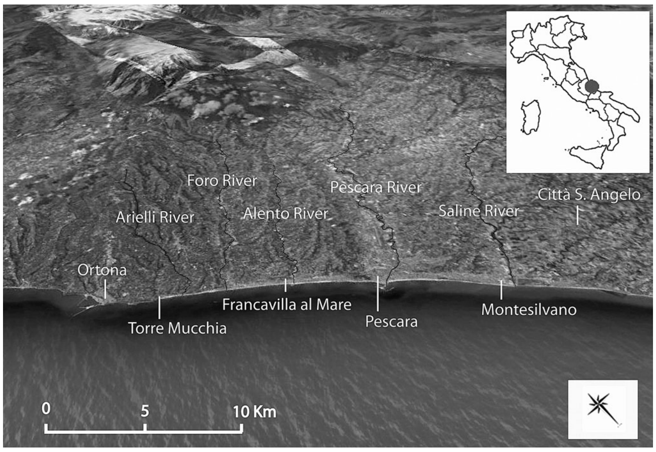

FIG. 2 - Location map of the Adriatic coast *(from Google Earth)*.

To the second type belongs a series of streams flowing only or mostly on prevailingly terrigenous sequences outcropping all along the coastal belt (Alento, Arielli and Foro rivers) (fig. 2).

According to the Köppen Climate System, the climate of the Adriatic coastal sector belongs to the humid mesothermal climate (C) Mediterranean type with very hot summer (Csa). Mean annual temperature calculated for the 1975-2009 period at Pescara and Ortona sites, is 15.7 °C, whilst mean temperature of the hottest month (July) is 24.5°C and of the coldest month is 8.4 °C at Ortona (January) and 7.5 °C at Pescara (February). Annual mean precipitation in the 1951-2010 period is 690 mm, ranging from a monthly 86.2 mm in the most humid month (December) down to 33.9 mm in the driest month (July). The absolute maximum daily rainfall is 216.4 mm recorded the 1st of March 1978 at Pescara station (see tab. 5 for more details).

TABLE 5 - Average climatic characteristics Abruzzo coast (Adriatic side)

Month	Mean temperature (°C) Min	Max	Mean	Mean rainfall (mm)	Rainy Days
Jan	4.6	10.8	8.3	64.1	7.2
Feb	4.7	11.3	8.0	50.3	6.8
Mar	7.0	14.0	10.6	55.0	7.0
Apr	9.6	17.0	13.4	50.0	6.4
May	14.1	21.8	17.9	38.9	5.3
Jun	17.7	25.8	21.7	40.9	4.9
Jul	20.2	28.7	24.5	33.9	3.7
Aug	20.1	28.7	24.4	45.3	4.0
Sep	16.7	25.0	20.9	66.7	5.6
Oct	13.4	20.8	17.2	77.4	7.2
Nov	8.9	15.5	12.2	81.3	8.2
Dec	5.8	12.0	8.9	86.2	8.6
Annual	**11.9**	**19.3**	**15.7**	**690.0**	**74.9**

Mean temperature and precipitation values of this coastal sector differ from those of the Tyrrhenian sector mainly for three geographic factors: i) sea; ii) exposure; iii) orography.

i) The Tyrrhenian Sea is deeper than the Adriatic Sea and thus has a higher thermal capacity. Consequence is that the Tyrrhenian sector has a higher maritime character with a mean annual temperature range of 15.2°C in comparison with 16.2°C of the Adriatic sector.
ii) During winter, the Adriatic sector is subject to the influence of continental polar air-masses incoming from north-eastern Europe. During summer the subtropical anticyclone acts on this area with lower intensity, in comparison with the Tyrrhenian one, because the Adriatic is in a marginal position to the centre of the high pressure.
iii) Moreover the Adriatic slope, sheltered by the Apennines, is leeward to perturbations incoming from the west. This brings on, in comparison with the Tyrrhenian slope, a lower mean annual precipitation with dryer winter (30 mm less, on average) and a more humid summer (60 mm more, on average).

4. RESULTS

4.1 Homogeneity and Trend Analysis

Some preliminary tests are carried out in order to check for the homogeneity of daily rainfall data. Both Buishand (1982)'s Q and R tests have been run, as well as the Wald-Wolfowitz randomness test (Wald and Wolfowitz, 1940). The latter is used assuming that when data are homogenous, discrepancies from the average values are purely random. In tab. 6 are displayed the results of the homogeneity and randomness tests on the daily rainfall for the 6 stations.

TABLE 6 - Results of homogeneity test on daily data
(* = 5% *significant*, ** = 1% *significant*)

Tests Statistics	Null Hypothesis	Roma - C R	Civitavecchia	Ostia	Ardea	Pescara	Ortona
Buishand's Q	*Homogeneity*	0.97	1.96**	1.48*	0.95	2.15**	1.20
Range Statistics	*Homogeneity*	1.71*	2.36**	1.72*	1.59	2.71**	2.43**
Test of Randomness	*Randomness*	-41.08**	-40.70**	-44.13**	-44.89**	-34.36**	-35.84**

All series excepted Pescara and Civitavecchia are homogenous at 1% level of significance. For Ardea both *Q* and *R* statistics do not reject the null hypothesis of homogeneity at 5% level. Data are not random as they show some structural patterns such as cycles and seasonality.

Also, the ADF test (Augmented Dickey Fuller) is run to check for the presence of unit roots, i.e. stochastic trend (see Dickey & Fuller, 1979 for further details). No stochastic trends are present as confirmed by the unit root tests (ADF) which reject the null hypothesis for all series (see tab. 7).

In order to check for the presence of trends in the annual maxima, some parametric and nonparametric tests are run for all the 6 rainfall stations. Results are displayed in tab. 8, from which we conclude that there are no linear trends in the annual maxima, excepted Pescara, for which rainfall maxima are decreasing in time. This results holds when both parametric (linear trend with parameters α, β) and nonparametric tests are run.

TABLE 7 - Results of stationarity test on daily data
(Zero-mean specification, lag 12) * = 5% *significant*, ** = 1% *significant*

Tests Statistics	Null Hypothesis	Roma - C R	Civitavecchia	Ostia	Ardea	Pescara	Ortona
Aug Dickey-Fuller	*Non-Stationarity*	-11957.1**	**-11899.1	-11870.2**	-12403.2**	-12482.9**	-12519.4**

TABLE 8 - Trend test Statistics of the annual maximum daily rainfall
(* = 5% *significant*, ** = 1% *significant*)

	Parametric test		*Non parametric tests*		
Gauge Station	**A**	**B**	**Pearson**	**Spearman**	**Kendall**
Roma CR	56.52**	-0.006	-0.005	-0.004	-0.009
Ostia	73.40**	-0.0301	-0.199	-0.18	-0.113
Civitavecchia	63.66**	-0.15	-0.107	-0.018	-0.009
Ardea	57.07**	0.11	0.095	0.095	0.055
Ortona	72.32**	-0.15	-0.073	-0.035	-0.018
Pescara	83.37**	-0.52	-0.248	**-0.284***	**-0.201***

When monthly series of 1-day maximum rainfall are considered over the years 1951-2009, there is evidence of a significant decreasing trend of maximum monthly rainfall in the winter season for Pescara and Civitavecchia. On the opposite, for Rome CR it is observed an increasing trend of maximum monthly rainfalls during the month of April.

4.2 Extreme Values Analysis

The extreme values analysis is carried out following two approaches: the first one is based on the maximum annual daily rainfall series (1-day, 2-day and 3-day) for which suitable probability distributions are fitted, whereas the second one is based on the series of POT for which the best fitting Generalized Pareto distribution is identified. The aim of this analysis is to estimate the return levels for various return periods (2, 5, 10, 25, 50, 100-year time) for each site. The fitted distributions for maxima and extreme values of stationary series are known to be strictly related under some regularity conditions (see Coles, 2001 for further discussion).

4.2.1 Annual Maximum Series

In the first approach, the 1-day, 2-day and 3-day annual maximum rainfall series are fitted by several probability distributions. In particular, the Generalized Extreme Value (GEV), Lognormal and Gamma distributions, which are the best fitting according to the Goodness of Fit tests (Kolmogorov-Smirnov, Cramer-Von Mises and Anderson-Darling GOF) and their estimated parameter as well as the corresponding return levels are displayed in tab. 9.

From the density plots and the parameter estimates of the fitted distributions to the various annual maximum rainfall

TABLE 9 - Return levels and parameters of the fitted distributions to 1, 2, 3-day maximum annual rainfall observed in the 6 stations.
(Highest return levels over the sites in bold)

		Roma C.R.			Civitavecchia			Ostia			Ardea			Pescara			Ortona		
		GEV	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**
1-day	location	μ 46.01652	α 7.62	μ 3.97	μ 48.29784	α 7.44	μ 4.02	μ 53.02782	α 8.64	μ 4.11	μ 50.64031	α 9.73	μ 4.05	μ 50.86934	α 4.91	μ 4.114	μ 50.91028	α 4.26	μ 4.09
	scale	σ 15.42826	(L 5.35; U 10.85)	(L 3.87; U 4.06)	σ 16.23407	(L 5.2; U 10.66)	(L 3.92; U 4.11)	σ 14.64358	(L 6.06; U 12.31)	(L 4.02; U 4.19)	σ 15.24471	(L 6.74; U 14.05)	(L 3.96; U 4.13)	σ 18.30401	(L 3.45; U 6.98)	(L 4; U 4.23)	σ 22.33872	(L 3; U 6.05)	(L 3.96; U 4.22)
	shape	ξ 0.097836	β 7.42	σ 0.36	ξ 0.096625	β 7.98	σ 0.37	ξ 0.162697	β 7.45	σ 0.33	ξ 0.048266	β 6.2	σ 0.32	ξ 0.271761	β 13.86	σ 0.4332	ξ 0.135953	β 15.86	σ 0.48
			(L 5.15; U 10.68)	(L 0.31; U 0.45)		(L 5.5; U 11.57)	(L 0.31; U 0.45)		(L 5.18; U 10.73)	(L 0.28; U 0.4)		(L 4.25; U 9.03)	(L 0.27; U 0.4)		(L 9.56; U 20.08)	(L 0.37; U 0.54)		(L 10.93; U 23)	(L 0.41; U 0.6)
		return level			return level			return level			return level			return level			return level		
	2	51.77	54.07	52.86	54.35	56.73	55.42	58.56	*61.91*	60.69	56.28	58.21	57.2	57.92	**63.43**	61.19	59.31	62.33	59.78
	5	70.94	72.65	71.8	74.50	76.48	75.39	77.90	*81.73*	79.85	74.35	75.64	75.06	84.76	91.59	88.12	88.08	**92.44**	89.9
	10	84.85	83.83	84.26	89.11	88.39	88.54	92.82	*93.57*	92.17	86.88	85.97	86.52	107.67	109.09	106.62	**109.72**	11.38	111.27
	25	103.96	96.92	99.95	109.14	102.35	105.11	*114.47*	107.35	107.4	103.37	97.96	100.67	**144.16**	129.98	130.65	140.42	134.14	139.69
	50	119.32	106.03	111.6	125.24	112.06	117.43	*132.84*	116.91	118.55	116.09	106.24	111.02	**178.00**	144.72	148.98	165.89	150.28	161.8
	100	135.65	114.67	123.24	142.33	121.29	129.73	*153.26*	125.95	129.57	129.16	114.05	121.23	**218.64**	155.83	167.66	193.70	165.79	184.66
		GEV	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**
2-days	location	μ 59.08498	α 8.86	μ 4.21	μ 63.94528	α 7.62	μ 4.27	μ 65.84515	α 7.83	μ 4.35	μ 67.11755	α 11.09	μ 4.29	μ 68.15568	α 5.75	μ 4.37	μ 65.1521	α 5.07	μ 4.36
	scale	σ 17.55882	(L 6.62; U 12.63)	(L 4.13; U 4.3)	σ 22.83628	(L 5.32; U 10.91)	(L 4.17; U 4.47)	σ 17.52306	(L 5.5; U 11.14)	(L 4.26; U 4.44)	σ 20.3736	(L 7.67; U 16.03)	(L 4.21; U 4.38)	σ 25.68472	(L 4.03; U 8.19)	(L 4.26; U 4.48)	σ 23.49061	(L 3.56; U 7.21)	(L 4.24; U 4.72)
	shape	ξ 0.123152	β 8.08	σ 0.33	ξ -0.01717	β 10.07	σ 0.37	ξ 0.293041	β 10.53	σ 0.34	ξ -0.13481	β 6.91	σ 0.31	ξ 0.129677	β 15.1	σ 0.41	ξ 0.260718	β 17.08	σ 0.43
			(L 5.61; U 11.63)	(L 0.28; U 0.41)		(L 6.95; U 14.61)	(L 0.31; U 0.46)		(L 7.31; U 15.17)	(L 0.29; U 0.42)		(L 4.74; U 10.08)	(L 0.26; U 0.38)		(L 10.43; U 21.86)	(L .35; U 0.51)		(L 11.79; U 24.75)	(L 0.37; U 0.53)
		return level			return level			return level			return level			return level			return level		
	2	65.67	68.88	67.55	72.29	73.4	71.75	72.63	*78.95*	77.23	74.40	74.4	73.26	77.80	**81.8**	79.34	74.19	80.93	78.17
	5	88.01	90.61	89.33	97.76	98.62	97.9	98.85	*105.67*	103.03	94.79	95.1	94.77	110.68	114.88	112.31	108.27	**116.18**	112.22
	10	104.62	103.57	103.38	114.35	113.81	115.17	121.68	*121.73*	119.79	106.66	107.28	108.42	135.27	135.19	134.68	137.06	**138.03**	135.56
	25	127.92	118.64	120.81	135.02	131.59	136.95	*158.72*	140.5	140.67	120.05	121.34	125.15	169.97	159.25	163.47	**182.49**	164.07	165.83
	50	147.05	129.09	133.6	150.13	143.96	153.17	*193.66*	153.56	156.05	128.94	131.02	137.3	198.61	176.15	185.26	**224.24**	182.42	188.89
	100	167.75	138.97	146.25	164.95	155.69	169.39	*236.26*	165.94	171.33	136.96	140.14	149.24	229.74	192.27	207.33	**274.00**	199.99	212.36
		GEV	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**	**GEV**	**Gamma**	**Lognormal**
3-days	location	μ 64.59367	α 8.53	μ 4.31	μ 70.40672	α 7.77	μ 4.38	μ 73.8984	α 7.45	μ 4.46	μ 77.4014	α 11.11	μ 4.43	μ 71.74696	α 5.68	μ 4.43	μ 72.46163	α 5.62	μ 4.46
	scale	σ 18.33537	(L 5.99; U 12.16)	(L 4.22; U 4.4)	σ 24.41751	(L 5.43; U 11.14)	(L 4.28; U 4.47)	σ 21.29172	(L 5.23; U 10.6)	(L 4.37; U 4.55)	σ 23.78613	(L 7.69; U 16.06)	(L 4.35; U 4.51)	σ 27.52281	(L 3.99; U 8.09)	(L 4.32; U 4.54)	σ 25.13451	(L 3.95; U 8)	(L 4.35; U 4.57)
	shape	ξ 0.190458	β 9.28	σ 0.33	ξ 0.015407	β 10.91	σ 0.36	ξ 0.247876	β 12.44	σ 0.35	ξ -0.17188	β 7.91	σ 0.31	ξ 0.134416	β 16.16	σ 0.42	ξ 0.256056	β 16.88	σ 0.41
			(L 6.44; U 13.36)	(L 0.28; U 0.41)		(L 7.53; U 15.82)	(L 0.31; U 0.45)		(L 8.63; U 17.92)	(L 0.3; U 0.44)		(L 5.42; U 11.52)	(L 0.26; U 0.38)		(L 11.16; U 23.39)	(L .36; U 0.52)		(L 11.66; U 24.43)	(L 0.35; U 0.51)
		return level			return level			return level			return level			return level			return level		
	2	71.55	76.11	74.59	79.38	81.23	79.44	82.07	*88.53*	86.49	85.85	85.25	83.95	82.09	86.41	83.79	82.12	**89.27**	86.53
	5	96.43	100.63	98.77	107.46	108.82	107.75	112.58	*119.35*	116.45	108.85	108.94	108.7	117.49	121.6	119.14	118.42	**125.85**	122.32
	10	116.11	115.29	114.39	126.32	125.41	126.36	138.05	*137.93*	136.04	121.79	122.88	124.42	144.07	143.23	143.21	**148.96**	148.35	146.57
	25	145.36	132.37	133.78	150.46	144.81	149.75	*177.80*	159.7	160.57	135.93	138.97	143.69	181.73	168.86	174.26	**196.95**	175.02	177.78
	50	170.74	144.22	148.02	168.60	158.3	167.13	*213.96*	174.86	178.72	145.02	150.05	157.7	212.95	186.86	197.82	**240.89**	193.76	201.35
	100	199.53	155.43	162.118	186.81	171.1	184.47	*256.65*	189.25	196.79	153.02	160.49	171.47	246.99	204.04	221.71	**293.08**	211.65	225.23

series we can conclude that there is a different pattern in the occurrence of extreme events for the western coast with respect to the eastern coast. Specifically, on the Tyrrhenian side extreme rainfalls are more likely to happen in correspondence of longer time spans (i.e. 3-day series) as the effect of cumulated stable rainfalls over time. This is the case for Ostia and Roma sites, where the shape parameter of the estimated GEV distribution increases for longer time spans, as reported in tab. 9. On the opposite, for the Adriatic coast extremes are more frequent in shorter time spans (1-day), as it is the case for Pescara. This is confirmed by a decreasing behavior of the shape of the fitted GEV for longer time-span. Ardea and Civitavecchia present a distribution of annual maximum rainfall well approximated by a Gumbel distribution (shape close to 0), with the greatest location parameter for the annual 3-day maximum rainfall obtained in correspondence to Ardea station (77.4 mm). Rome and Civitavecchia displays the lowest location estimates for 1, 2 and 3-day distributions of the annual maximum. The highest scale estimates of the fitted distributions are obtained for Pescara and Ortona.

4.2.2 Partial Duration Series (POT analysis)

In the peak over threshold (POT) analysis a Generalized Pareto Distribution is fit on the 95th percentile exceedances.

The choice of the 95th percentile is based on the mean residual life plots, which are often used to select the appropriate threshold for the POT analysis. The most suitable threshold is the smallest threshold value where the plot is nearly linear. Also, threshold plots can be used as a tool for detecting the most reliable threshold. Indeed, it is defined as the highest threshold after which the parameters of the fitted GPD loose their stability. Fig. 3-8 display the two plots for each of the rainfall stations considered in the analysis.

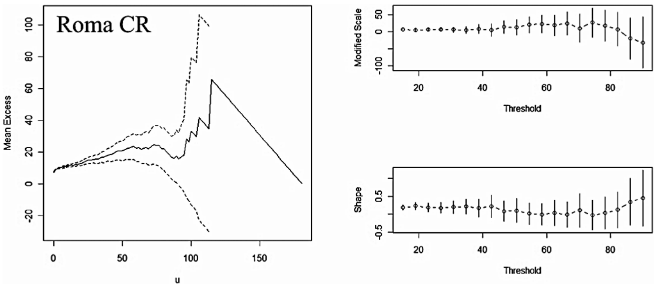

FIG. 3 - Mean Excess and Threshold plots: Roma - Collegio Romano (CR).

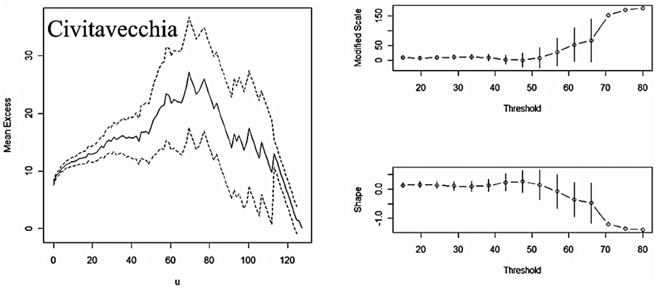

FIG. 4 - Mean Excess and Threshold plots: Civitavecchia.

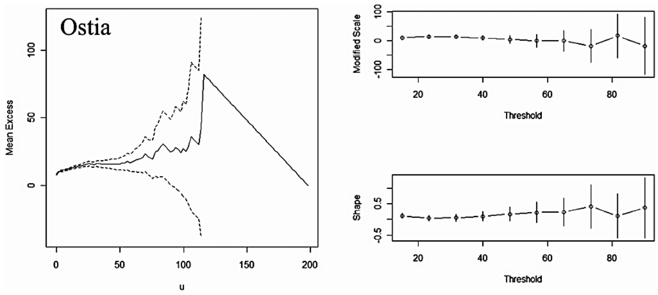

FIG. 5 - Mean Excess and Threshold plots: Ostia.

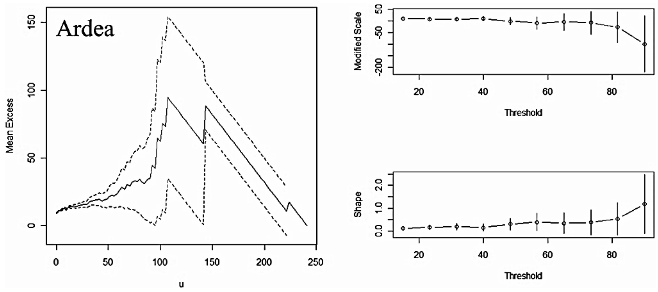

FIG. 6 - Mean Excess and Threshold plots: Ardea.

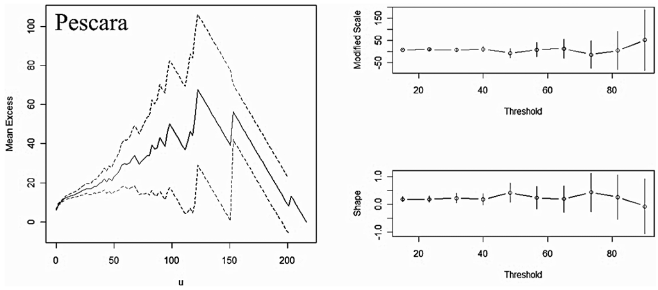

FIG. 7 - Mean Excess and Threshold.

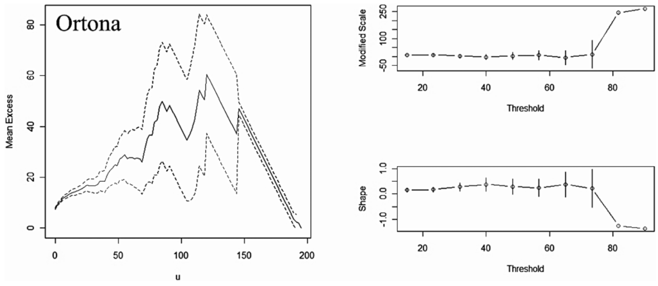

FIG. 8 - Mean Excess and Threshold plots: Ortona.

From the visual inspection of the plots, we observe that for almost all sites the ideal threshold level is around the 95th percentile. Overall, all sites present a similar behavior of the mean excess plot being linear until 40 mm of rain and presenting stable shape and scale estimates for the GPD up to the same value. For Ardea we observe that the suggested threshold is slightly over the 40 mm obtained for the other sites.

The GPD approach considered so far looks at exceedances over a threshold and those values are fit to a Generalized Pareto distribution. A more theoretically appealing way to analyze extreme values is to use a Point Process (PP) characterization, which has the advantage to unify all the previously discussed models in the interpretation of extremes. Indeed, the parameters of the point process model can be expressed in terms of the parameters of the GEV distribution or, equivalently, in terms of the parameters of a Poisson process and of the Generalized Pareto Distribution under some regularity conditions on the data (see Coles, 2001).

Dependence issues constitute another major issue in rainfall time series. Indeed, much of the theory applied so far assumes the independence of data, which may not be the case when looking at extreme values in time. Extreme rainfalls can persist in time, leading to consecutive days with high rainfall amounts exceeding the threshold. The exceedances would therefore occur in clusters, from which the need of a de-clustering procedure in order to identify within the sample approximately independent clusters of extremes. This avoids the short-range dependence of the time series. Therefore, de-clustering procedures are used as suggested by Ferro & Segers (2003). We use the extremal index, a parameter which measures the degree of clustering of extremes in a stationary process and takes values between [0,1]. Tab. 10 displays the estimated extremal index for each station, the corresponding number of clusters and the optimal run lengths. We observe that overall all stations present extremes which are not heavily clustered as indicated by values of the estimated extremal index ranging from 0.81 to 0.89 for all stations excepted Ardea, which achieves the lowest value 0.74. Then, on the de-clustered series of exceedances a GPD is fitted by maximum likelihood estimation (MLE) with parameter estimates and the corresponding return levels reported in tab. 11.

The GPD model was fitted to the series of exceedances in order to estimate the recurrence interval (1 in 5, 10, 25, 50 and 100 years) using the R software (package ISMEV) (cran.r-project.org/web/packages/ismev/index.html). The estimation of the parameters and the corresponding return levels are displayed in tab. 11.

TABLE 10 - Extremal Index estimates on rainfall exceedances over the 95th percentile threshold

	Threshold (mm)	**Extremal Index**	**Confidence Interval**	**N Clusters**	**Optimal run lenghts**
Roma CR	29	0.85	0.76 - 0.96	264	7
Civitavecchia	30	0.81	0.69 - 0.96	230	10
Ostia	34	0.83	0.73 - 0.94	256	9
Ardea	34	0.74	0.66 - 0.86	248	13
Pescara	31	0.86	0.74 - 0.98	257	7
Ortona	33	0.89	0.78 - 1.3	264	6

As a general comment, we notice that the return levels obtained with the POT analysis are higher than those obtained with the annual maxima approach for shorter return periods (i.e. for 2, 5 and 10-year return time), whereas for longer return periods, such as 25, 50 and 100-year, return levels estimated by POT are lower than those obtained using the annual maxima approach. This is because with the block maxima approach we capture more the magnitude of the rainfall extremes than the frequency of occurrence. On the contrary, the POT approach tends to give more importance to the frequency of extremes, despite their magnitude.

From the POT analysis we notice that there are substantial differences in the magnitude of extreme rainfalls of Pescara Metropolitan Region (PMR) with respect to the Rome Metropolitan Region (RMR). Indeed, the highest return levels at 2, 5, 10, 25, 50 and 100-year time are recorded on the Adriatic coast, reaching the 221.58 mm in a 100-year at Ortona station. This is due to the higher shape parameters estimated for the PMR sites related to the RMR ones.

4.2.3 Parameter variation

It is possible to allow parameters of the extreme value distribution to vary as a function of time or other covariates. For example, in addition to varying parameters of the GPD to account for dependencies, it is also possible to

TABLE 11 - Estimation of return levels based on Generalized Pareto (GPD) model

	Roma C.R.			**Civitavecchia**			**Ostia**			**Ardea**			**Pescara**			**Ortona**		
	GPD			GPD			GPD			GPD			GPD			GPD		
location	u	29	Nr Ex.	u	30	Nr Ex.	u	34	Nr Ex.	u	34	Nr Ex.	u	31	Nr Ex.	u	33	Nr Ex.
scale	σ	13.83	205	σ	15.31	175	σ	16.19	199	σ	17.61	194	σ	14.69	199	σ	12.61	206
shape	ξ	0.1		ξ	0.07		ξ	0.05		ξ	0.09		ξ	0.22		ξ	0.28	
	return level			**return level**			**return level**			**return level**			**return level**			**return level**		
2		58.40			59.56			66.53			65.60			65.72			65.65	
5		74.62			75.93			83.22			78.65			88.23			88.47	
10		87.95			88.99			96.36			87.85			108.48			110.10	
25		107.10			107.23			114.25			99.17			140.37			146.05	
50		122.85			121.80			128.68			107.14			169.07			180.13	
100		139.77			137.06			143.42			114.65			202.41			221.58	

vary the threshold, thus allowing for modeling exceedances during a lower point in the cycle.

In particular, we consider a time-varying threshold computing the 95th percentile of effective annual rainfall for each year. We check for the presence of a linear trend by fitting a simple regression over the thresholds, whose estimated coefficients are reported in tab. 12. The obtained estimates confirm the evidence that trend coefficients are in general negative or not significantly different from 0, as displayed in the annual 95th percentile plots (fig. 9). For Ardea site we observe a general high variability of the annual 95th percentiles in the first 25 years of the period considered and a remarkable decrease of peaks and troughs from the 70s on. As in the case of Ortona, it is not observed a clear constant cyclical pattern during the time period under study. For both stations we suspect a structural break around the year 1975. Concerning Civitavecchia, Ostia and Pescara we notice a regular pattern of the thresholds every 10-12 years, approximately. The length of such a cyclical pattern is lower than the one observed in Rome, which is roughly about 18-20 years.

TABLE 12 - Estimated coefficients of the time-varying equation fitted to the POT series

	Roma C.R.		**Civitavecchia**		**Ostia**		**Ardea**		**Pescara**		**Ortona**	
Parametric	α	β	α	β	α	β	α	β	α	β	α	β
u(t)=α+βt	29.96	0.01	32.19	-0.04	35.38	-0.01	37.74	-0.02	32.89	-0.05	36.89	-0.1
time varying parameters												
Location												
μ0		50.59		19.2		25.56		-1.04		48.34		55.08
μ1		0		0.002		0.002		0.01		0		0
Scale												
σ0		2.93		2.9		3.7		3.59		2.92		3.01
σ1		0.32		-0.13		0.44		0.39		0.6		0.23
σ2		-0.37		0.19		-0.35		-0.27		-0.23		-0.07
Shape												
ξ		0.15		-0.22		0.32		-0.19		-0.12		0.27

In order to study the temporal change in extreme rainfall, we model the series of extremes by a Point Process which allows the parameters to vary with time. Specifically, we consider a linear trend for the threshold, whose estimated coefficients are displayed in tab. 12, a linear trend for the location coefficient, as

$$\mu(t) = \mu_0 + \mu_1 t$$

where μ_0 is the intercept of the trend line, μ_1 is the slope and t = 1,…,T represents the year.

A cyclically varying scale is assumed to be function of the year t and to follow the sinusoidal process

$$\sigma(t) = \sigma_0 + \sigma_1 \sin \frac{2\pi t}{365.25} + \sigma_2 \cos \frac{2\pi t}{365.25}$$

with real parameters σ_0, σ_1 and σ_2. The shape ξ(t) = ξ is assumed to be constant through time. The estimated para-

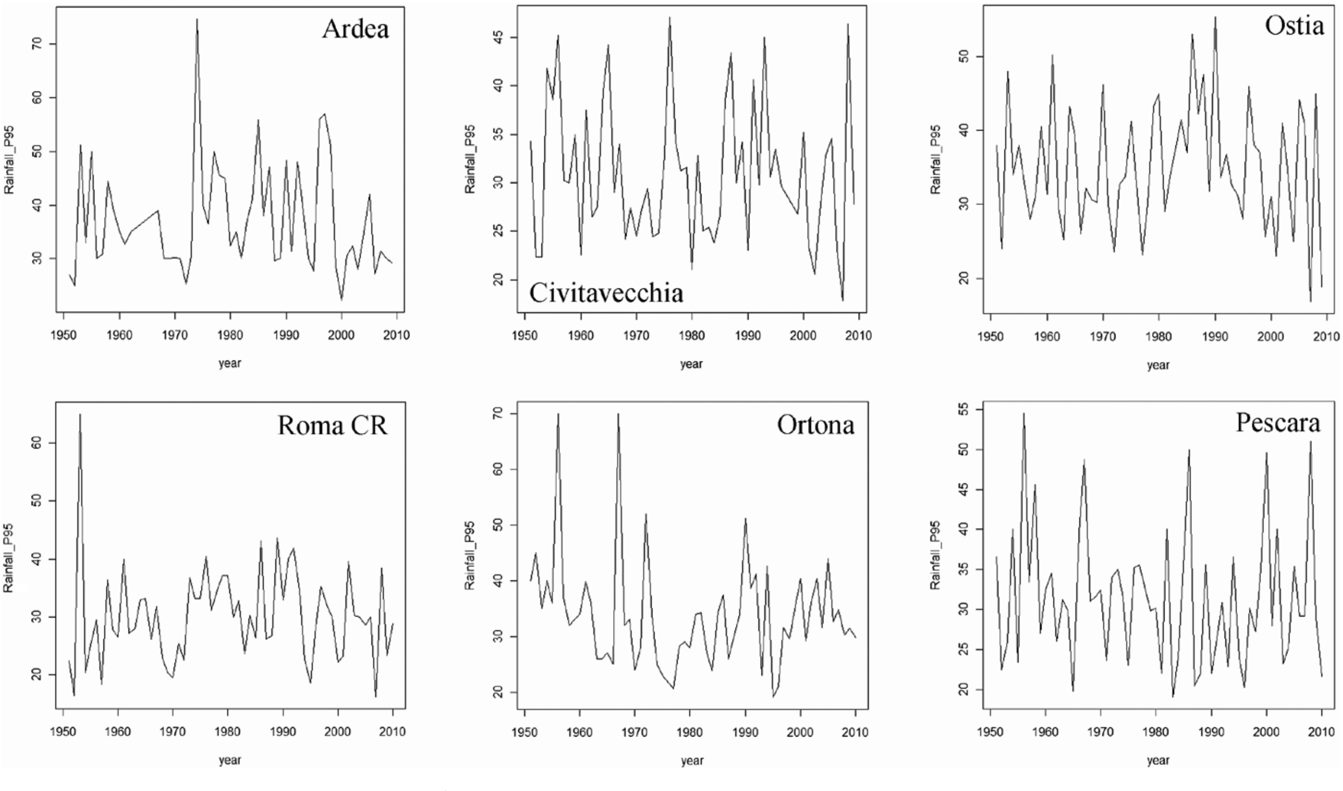

FIG. 9 - Annual 95th percentiles plots: Rome, Civitavecchia, Ostia, Ardea,Pescara, Ortona.

meters for the time-varying location and scale equations are reported in tab. 12. From the displayed results we can conclude that in general there is no evidence of a linear trend in the threshold which has a mean value α which coincides almost for each gauging station to the 95th percentile calculated over the entire period under study (1951-2009). Ardea and Ostia both display a decreasing trend of the thresholds, the former from the 1975 onwards, the latter during the last 20 years. As for Ortona, the 95th percentiles tend to decrease over the whole period of observation.

As for the other time-varying coefficients, we notice similar values for scale and shape parameters across all the sites, which is not the case for the location equation coefficients. Indeed, the hypothesis of a GPD with a time-varying location coefficient is coherent with Ardea rainfall thresholds.

5. CONCLUSIONS

Extreme rainfalls in metropolitan areas represent an important natural hazard especially along the northern Tyrrhenian Latian coast which is fed by small rivers that are the main responsible for severe local flash floods.

The statistical methodology used in this paper not only is suitable to answer the research question underlying this piece of research, but also has the advantage to be applicable to other case studies in different regions. The main limitations are related to data availability through time and definitely to their quality. The presence of gaps, i.e. missing observations, of frequent changes in the gauging instruments and of the position of gauging stations are serious threats to the reliability and quality of results.

From the analysis carried out there are no linear trends in the annual maxima for all stations, excepted for Pescara metropolitan area, which shows a decreasing pattern in time.

The main conclusion we can draw from the extreme value analysis is that there are substantial differences in the magnitude of extreme rainfalls of PMR with respect to the RMR. Indeed, the highest return levels at 2, 5, 10, 25, 50 and 100-year time are recorded on the Adriatic coast, reaching the 221.58 mm in a 100-year at Ortona station. This is due to the higher shape parameters estimated for the PMR sites related to the RMR ones.

Moreover, we find evidence of a different pattern in the occurrence of extreme events for the western coast with respect to the eastern coast. Specifically, on the Tyrrhenian side extreme rainfalls are more likely to happen in correspondence of longer time spans (i.e. 3-day series) as the effect of cumulated stable rainfalls over time. On the contrary, for the Adriatic coast extremes are more frequent in shorter time spans (1-day), as it is the case for Pescara. A possible explanation of this finding is that climate is much more instable on the Adriatic coast than the Tyrrhenian one due to high variation in the low pressure cells.

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