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Extreme Rainfall Event Analysis Using Rain Gauges in a Variety of Geographical Situations

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Abstract

About 30 years of measurements made by the rain gauges located in Piedmont (Italy) have been analyzed. Rain gauges have been divided into 4 datasets considering the complex orography near Turin, namely the flatlands, mountains, hills and urban areas. For each group of gauges, the Generalized Extreme Values (GEV) distributions are estimated considering both the entire dataset of available data and different sets of 3 years of data in running mode. It is shown that the GEV estimated parameters temporal series for the 3 years dataset do not present any specific trend over the entire period. The study presented here is preliminary to a future extreme rainfall event analysis using high temporal and spatial resolution X-band weather radar with a limited temporal availability of radar maps covering the same area.

Keywords

Rain Gauges, Extreme Rainfall Events, Generalized Extreme Value, GEV

1. Introduction

Extreme rainfall events analysis could be very significant if it is possible to put in evidence trends related to climate change and their impacts on the society [1] [2].

A large number of theoretical modelling and empirical analyses have been performed suggesting that changes in frequency and intensity of extreme events, including also extreme floods, may occur even in relations to small changes in climate [3]-[8] making extreme rainfall events analysis even more important.

Extreme rainfall event analyses have been made almost all over the world considering in particular rain

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gauges data or climatological models (e.g. [1] [9]-[11]). But up to now, very few analyses have been performed exploiting weather radars. The most important example of extreme rainfall event analysis using radar data is related to a Dutch region and presented in a set of papers of A. Overeem [12]-[15]. A climatological analysis is presented exploiting C-band Doppler radar data with a spatial resolution of 2.4 km and 10 years of historical data. The Generalized Extreme Value (GEV) distributions are evaluated as well as the radar depth-duration curves over small selected basins demonstrating that radar systems may be a useful tool to analyze extreme events. Of course, in this case the orography is homogeneous.

In particular in the Piedmont region (North-Western part of Italy), the orography is extremely complex and flash floods in small basins are causing large damages. Consequently it is important to evaluate the extreme distribution functions of such events and to find out if there are climatological trends causing significant changes in the distribution parameters.

In the present paper, the available data from a set of rain gauges are examined to this end as well as preliminary study for a future analysis using X-band weather radar installed in Turin.

2. Rain Gauges Data

In Piedmont, around the town of Turin, a set of meteorological stations, managed by ARPA Piemonte, are installed. They are equipped with a set of different sensors including rain gauges. Measured data are available and can be downloaded freely on internet. They have been used in the in the statistical analysis of extreme events reported in the following. In particular it is used the cumulative daily rainfall data available for each day.

Seventeen fully operative weather stations equipped with rain gauges have been identified in a 30 km radius circle around Turin.

2.1. Rain Gauges Groups

The rain gauges have been divided into 4 homogeneous groups, taking into account their installation environment.

The 4 zones are the following (see also in the following **Tables 1-4** and **Figure 1**):

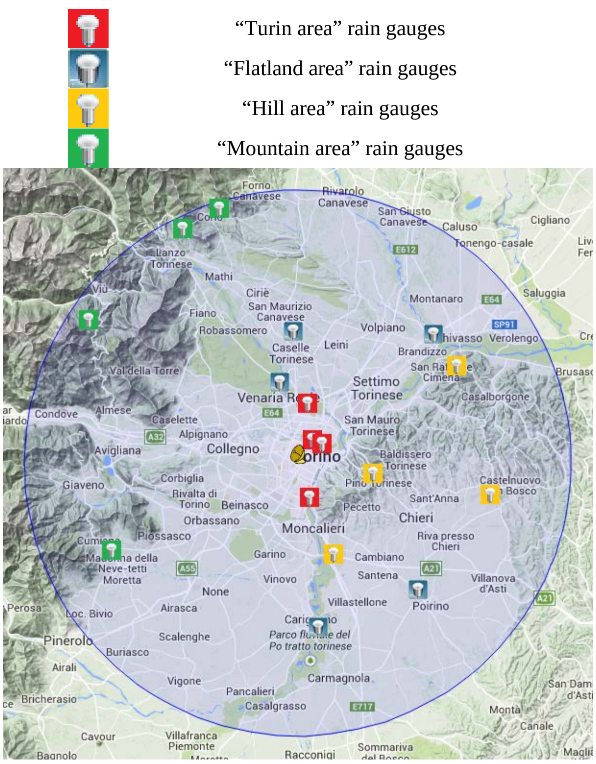

Figure 1. Rain gauges grouped identified in each area within a 30 km radius circle.

Table 1. Rain gauges in the "Mountains area".

Rain gauge name	UTM X [m]	UTM Y [m]	Lat [°]	Long [°]
Corio	386,008	5,018,529	45.3110	7.5458
Cumiana	373,174	4,980,375	44.9655	7.3918
Lanzo	381,885	5,016,336	45.2906	7.4937
Niquidetto	371,184	5,006,333	45.1987	7.3599

Table 2. Rain gauges in the "Hillsarea".

Rain gauge name	UTM X [m]	UTM Y [m]	Lat [°]	Lon [°]
Bauducchi	398,228	4,979,528	44.9619	7.7096
Castagneto Po	412,336	5,000,464	45.1522	7.8848
Pino Torinese	402,828	4,988,482	45.0431	7.7662
Buttigliera d'Asti	416,001	4,985,910	45.0217	7.9338

Table 3. Rain gauges in the "Flatlandsarea".

Raingaugename	UTM X [m]	UTM Y [m]	Lat [°]	Lon [°]
Brandizzo Malone	409,882	5,004,010	45.1838	7.8529
Caselle	394,093	5,004,633	45.1872	7.6519
Venaria Ceronda	392,460	4,998,970	45.1360	7.6323
Carmagnola	396,316	4,971,343	44.8880	7.6870
Poirino Banna	407,716	4,975,370	44.9258	7.8306

Table 4. Rain gauges in the "Turin area".

Raingaugename	UTM X [m]	UTM Y [m]	Lat [°]	Lon [°]
Torino Giardini Reali	397,112	4,991,946	45.0735	7.6929
Torino ReissRomoli	395,535	4,996,506	45.1143	7.6719
Torino Vallere	395,596	4,985,890	45.0188	7.6749
Torino Via della Consolata	396,054	4,992,433	45.0777	7.6794

- Mountains area.
- Hills area.
- Flatlands area.
- Turin area.

2.2. Temporal Availability of Rain Gauges Data

The rain data are available on the archive accessible on internet since 1988. Since we ended the analysis the 30th June 2014, it means that some rain gauges have been operative for more than 26 years. However, due to maintenance reasons and newer installations, each meteorological station has its own period of operation often smaller than 26 years, as reported in the following table (Table 5).

3. GEV Distribution for Extreme Rainfall Events Analysis

3.1. GEV Distribution and Parameters

The extreme rainfall event analysis using rain gauges data has been performed by estimating the GEV distribu-

Table 5. Operational interval of each rain gauge (date in dd/mm/yy format).

Raingaugename	Start date	End date
Bauducchi	16/06/1993	30/06/2014
Brandizzo Malone	01/01/2005	30/06/2014
Caselle	19/11/2003	30/06/2014
Castagneto Po	01/06/2002	30/06/2014
Corio	01/01/2001	30/06/2014
Cumiana	27/01/2008	30/06/2014
Lanzo	24/08/1989	30/06/2014
Niquidetto	04/09/1999	30/06/2014
Pino Torinese	19/05/1988	30/06/2014
Venaria Ceronda	24/12/1997	30/06/2014
Carmagnola	10/06/1993	30/06/2014
Poirino Banna	01/01/1996	30/06/2014
Buttigliera d'Asti	26/03/2005	30/06/2014
Torino Giardini Reali	06/08/2004	30/06/2014
Torino ReissRomoli	01/01/2004	30/06/2014
Torino Vallere	18/01/2001	30/06/2014
Torino Via della Consolata	19/12/2003	30/06/2014

tion parameters. Therefore it has been assumed that the hypothesis of the GEV theory is satisfied, which is a common choice when an extreme event analysis is performed.

The expression of the common GEV distribution is reported Equation (1): k is the shape factor, σ is the scale parameter and μ is called location parameter.

$$F(x,\mu,\sigma,k)=\exp\left\{-\left[1+k\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{k}}\right\} \tag{1}$$

It is well known that the GEV distribution parameters can be made using two different methods: the maximum likelihood (ML) estimation method and the L-moment method. Since the ML method is more robust also for a small number of data [16], GEV parameters (k, σ, μ) estimations were obtaining using a MATLAB© routine implementing such method.

3.2. Definition of Extreme Rainfall Event

It is necessary to establish when a rainfall event is considered "extreme" and, therefore, which is the dataset to use for the estimation of the GEV distribution parameters.

Three different methods have commonly been used to identify extreme rainfall events:

- The *Peaks Over Threshold* (POT) using rainfall depth thresholds over a specified time interval.
- The *Peaks Over Threshold* (POT) using probabilistic thresholds, such as the 90th and 99th percentiles of precipitation, over a specified time interval. In this way it is possible to define and discriminate heavy and very heavy events.
- The *Block Maxima* (BM), calculating the return periods of the event based on a specific interval maximum on 24 hours precipitation series.

For the analysis of extreme event reported in this paper, the POT approach is followed and two different definitions of extreme events are considered:

- *Threshold* T_1 = 40 mm/day: an event is considered as extreme, for a single rain gauge, when during 24 hours more than 40 mm of cumulated rain are measured. It corresponds to almost the 90^{th} percentile of the precipitation distribution.
- *Threshold* T_2 = 50 mm/day: an event is considered as extreme, for a single rain gauge, when during 24 hours more than 50 mm of cumulated rain are measured. It corresponds to almost the 95^{th} percentile of the precipitation distribution.

4. Data Processing and Results

The GEV distribution parameters were estimated examining the entire period of available rain gauges data corresponding to 26 years that is from 1998 to 2014.

However there is a general feeling that the climate is changing, and in particular the "extremes" may be significantly affected. Therefore it is of great interest to be able to put in evidence any change in the GEV distribution, possibly over not so long time interval. For this reason, we subdivided the available data set in 3 years groups, in order to see if some systematic changes in the GEV distribution may be put in evidence, well aware of the poor significance of any results that could be obtained in this way.

The 3 years groups of rain gauges data were examined in "running mode" for both rain thresholds, T_1 and T_2 over the entire period 1988-2014.

As reported in Section 2, the rain gauges were divided in the four geographical areas (Mountains area, Hills area, Flatlands area and Turin area) and the corresponding GEV distributions parameters were evaluate.

Table 6 (for T_1 = 40 mm/day) and **Table 7** (for T_2 = 50 mm/day) report the GEV distributions parameters k, σ, μ. In both tables it is possible to note that most of k parameters are positive. It means that the GEV distributions are Frechét distribution (or EV2, Extreme Value type 2, distribution) which are very common in hydrology research and applications.

Table 6. GEV distribution parameters for T_1 = 40 mm/day.

	MOUNTAINS AREA				HILLS AREA				FLATLANDS AREA				TURIN AREA			
YEARS	N° OP. GAUGES	k	σ	μ	N° OP. GAUGES	k	σ	μ	N° OP. GAUGES	k	σ	μ	N° OP. GAUGES	k	σ	μ
1988-1990	0	//	//	//	1	0.0001	6.9180	46.1939	0	//	//	//	0	//	//	//
1989-1991	1	0.5921	9.9683	49.0490	1	−1.1263	15.8497	59.7272	0	//	//	//	0	//	//	//
1990-1992	1	0.4637	10.0609	51.6365	1	1.1686	4.6151	43.9128	0	//	//	//	0	//	//	//
1991-1993	1	0.4860	11.5607	51.9723	2	0.6448	3.8738	44.3295	1	1.1349	1.2440	44.7688	0	//	//	//
1992-1994	1	0.6330	12.7494	52.8830	2	0.9239	4.3989	44.4027	1	3.6944	1.6359	44.2414	0	//	//	//
1993-1995	1	0.7197	12.3928	51.4016	2	1.2130	3.9712	43.4039	1	0.5346	4.0693	45.2434	0	//	//	//
1994-1996	1	0.6662	9.7409	50.6334	2	1.1319	4.6475	43.3616	2	0.5270	4.1872	45.3413	0	//	//	//
1995-1997	1	0.4424	6.9481	48.5471	2	0.5931	3.6545	43.3403	3	0.4414	4.0703	45.4754	0	//	//	//
1996-1998	1	0.4906	10.0281	52.1733	2	0.0410	5.4640	46.3848	3	0.4618	4.6153	45.7846	0	//	//	//
1997-1999	2	0.3530	15.7362	56.6529	2	−0.4122	7.4381	49.1545	3	0.2807	5.9352	47.9016	0	//	//	//
1998-2000	2	0.5719	18.7639	59.2012	2	0.1887	11.2918	52.1710	3	0.1965	9.1657	50.6755	0	//	//	//
1999-2001	3	0.5756	17.7348	57.4726	2	0.0726	13.7285	53.8674	3	0.1442	10.4337	53.1529	0	//	//	//
2000-2002	3	0.5904	13.2862	53.1479	2	−0.0554	13.7417	54.5280	3	0.3631	10.1725	49.4855	0	//	//	//
2001-2003	3	0.4587	10.1366	50.1417	3	0.3232	7.0174	46.2405	4	0.5593	6.6940	46.2676	1	0.6443	5.1380	46.7173
2002-2004	3	0.4865	8.7680	48.9325	3	−0.2274	9.3349	49.6499	4	0.7418	5.5613	44.8062	1	0.5585	4.8199	45.0039
2003-2005	3	0.3881	8.2759	48.2989	4	0.4846	4.4561	44.1046	5	4.4600	1.9910	40.8461	1	0.7731	3.6414	43.7100
2004-2006	3	0.6803	11.0680	50.0029	4	0.5120	8.7351	47.9720	5	0.7703	8.4255	46.6926	4	0.8620	5.5792	45.3305

Continued

2005-2007	3	0.5941	12.5096	51.9112	4	0.7987	6.0719	44.9527	5	0.6708	7.3748	46.6586	4	0.7242	6.0283	45.5581
2006-2008	4	0.2619	16.7762	58.2466	4	0.6754	5.6861	45.2202	5	0.6402	7.8101	47.3378	4	0.4122	7.1720	47.6286
2007-2009	4	0.1177	13.3982	55.9339	4	0.4945	5.4833	45.4095	5	0.5395	5.1941	45.0757	4	−0.0828	8.2041	49.3811
2008-2010	4	−0.0246	16.0427	60.8720	4	0.3595	5.8094	46.2443	5	0.5966	6.2063	45.8130	4	−0.0416	8.1839	51.3382
2009-2011	4	0.4662	13.4615	54.1995	4	0.1489	7.2879	48.4230	5	0.3395	6.5558	47.5404	4	0.0986	8.8878	51.5056
2010-2012	4	0.5605	13.4501	53.3085	4	0.2933	5.8212	46.5939	5	0.3747	6.9795	47.9197	4	0.1788	9.3536	51.1534
2011-2013	4	0.6042	10.4279	50.6064	4	0.3942	5.6920	46.0312	5	0.3329	6.2807	47.5575	4	0.5517	6.7894	46.4089
2012-2014	4	0.4666	8.7406	49.4015	4	0.5588	4.0474	44.2357	5	0.5490	5.4978	45.8810	4	0.7048	4.0665	43.7145
1988-2014	**ALL**	**0.5388**	**11.6510**	**51.7161**	**ALL**	**0.5669**	**5.9639**	**45.6937**	**ALL**	**0.5047**	**6.4928**	**46.6750**	**ALL**	**0.4123**	**7.1151**	**47.4071**

Table 7. GEV distribution parameters for $T_2 = 50$ mm/day.

	MOUNTAINS AREA				HILLS AREA				FLATLANDS AREA				TURIN AREA			
YEARS	**N° OP. GAUGES**	***k***	***σ***	***μ***	**N° OP. GAUGES**	***k***	***σ***	***μ***	**N° OP. GAUGES**	***k***	***σ***	***μ***	**N° OP. GAUGES**	***k***	***σ***	***μ***
1988-1990	0	//	//	//	1	0		0	0	//	//	//	0	//	//	//
1989-1991	1	0.5806	10.8670	59.7271	1	−1.5876	9.4706	67.8347	0	//	//	//	0	//	//	//
1990-1992	1	0.5683	9.6966	59.3485	1	−1.5876	9.4706	67.8347	0	//	//	//	0	//	//	//
1991-1993	1	0.5280	11.8845	61.8248	2	−2.0215	15.0321	66.3641	1	0	0	52.2000	0	//	//	//
1992-1994	1	0.7859	13.2706	61.2843	2	−1.4373	53.5602	86.5360	1	4.8509	0.8776	52.3809	0	//	//	//
1993-1995	1	0.8065	14.2835	62.0898	2	−1.4373	53.5602	86.5360	1	4.8509	0.8776	52.3809	0	//	//	//
1994-1996	1	1.3781	6.8363	54.8957	2	−1.3290	48.7865	87.0908	2	3.2888	0.1118	50.8336	0	//	//	//
1995-1997	1	1.1285	5.3076	54.2275	2	−1.2371	5.3719	58.4577	3	3.8650	0.1975	50.8510	0	//	//	//
1996-1998	1	0.8281	9.1278	57.4218	2	−0.3610	4.3080	55.0101	3	1.1738	3.7033	53.1793	0	//	//	//
1997-1999	2	0.3175	15.5003	66.9868	2	0.7879	1.9247	52.7812	3	0.5145	3.8462	54.2952	0	//	//	//
1998-2000	2	0.5829	19.9335	69.9485	2	0.7009	7.3211	57.0845	3	0.4562	5.8234	56.9785	0	//	//	//
1999-2001	3	0.4163	21.0775	70.4729	2	0.1518	10.5032	64.6230	3	0.5022	6.5422	57.3179	0	//	//	//
2000-2002	3	0.5477	14.7934	64.2704	2	−0.0236	10.3148	64.3121	3	0.1516	9.8393	60.9960	0	//	//	//
2001-2003	3	0.4090	10.2889	60.7514	3	−0.4960	7.6925	59.0111	4	−0.4035	9.8104	60.2950	1	4.6151	0.5704	53.7235
2002-2004	3	0.5816	8.3197	58.2862	3	−0.2726	6.2889	57.8034	4	−0.3304	9.1165	59.6729	1	4.6151	0.5704	53.7235
2003-2005	3	0.5604	6.8205	56.5929	4	−1.1612	6.5376	59.9699	5	−1.2200	7.8285	62.9830	1	3.6551	0.0350	71.4095
2004-2006	3	0.9374	10.2711	58.0839	4	0.2694	10.0431	60.2717	5	0.1258	13.9988	64.7480	4	1.1448	7.2532	55.4808
2005-2007	3	0.8393	10.9720	58.8442	4	0.2029	10.9448	61.2991	5	0.1510	14.3979	64.5242	4	0.4044	9.2279	58.6058
2006-2008	4	0.2395	15.7481	67.5252	4	0.4828	7.4773	56.8738	5	0.6596	10.5079	60.3006	4	0.6370	5.6484	55.6438
2007-2009	4	0.0192	12.7547	64.2971	4	0.1136	5.8440	57.5715	5	0.7013	6.8158	56.5110	4	0.0723	4.9840	56.9240
2008-2010	4	0.0406	13.5229	66.7912	4	0.3395	5.0482	55.0537	5	0.7786	7.0553	56.3876	4	0.5644	4.0506	55.2457
2009-2011	4	0.6543	12.0260	61.2153	4	0.2591	5.3467	56.2620	5	0.3626	6.7342	56.8738	4	0.7215	4.8569	54.5553
2010-2012	4	0.6450	13.6195	62.4102	4	0.3062	4.6680	55.3697	5	0.4681	6.8359	56.8280	4	0.7743	5.6112	55.0242
2011-2013	4	0.7911	10.9740	59.7070	4	0.2689	4.6251	57.5555	5	0.2923	6.2409	57.1092	4	1.2506	4.2261	53.2391
2012-2014	4	0.5214	8.9774	59.4156	4	3.7461	0.5199	55.5383	5	0.9004	4.8822	55.1968	4	1.0791	3.9685	53.7345
1988-2014	**ALL**	**0.6085**	**11.8615**	**61.0854**	**ALL**	**0.4263**	**6.5775**	**56.8874**	**ALL**	**0.6150**	**6.9433**	**56.6746**	**ALL**	**0.7311**	**5.3279**	**55.0701**

Figure 2 and **Figure 3** report the GEV parameters estimations: the green lines are the values of the corresponding parameters estimated by using all the available rain measurements during the 26 years interval. As appears also from the tables, the GEV parameters are not extremely different from one to the other geographical area, except for the value of σ significantly larger in the mountains area with respect to the others, as it can be expected due to the large variability of wind current and rain fields between the mountains.

In the same figures, the diagrams report the same parameters estimated over the 3 years intervals. It is quite evident that there are no significant trends in such estimates and no significant correlation from area to area.

5. Conclusions and Outlooks

The data analysis has shown that the GEV distribution parameters estimated over a long time period (26 years)

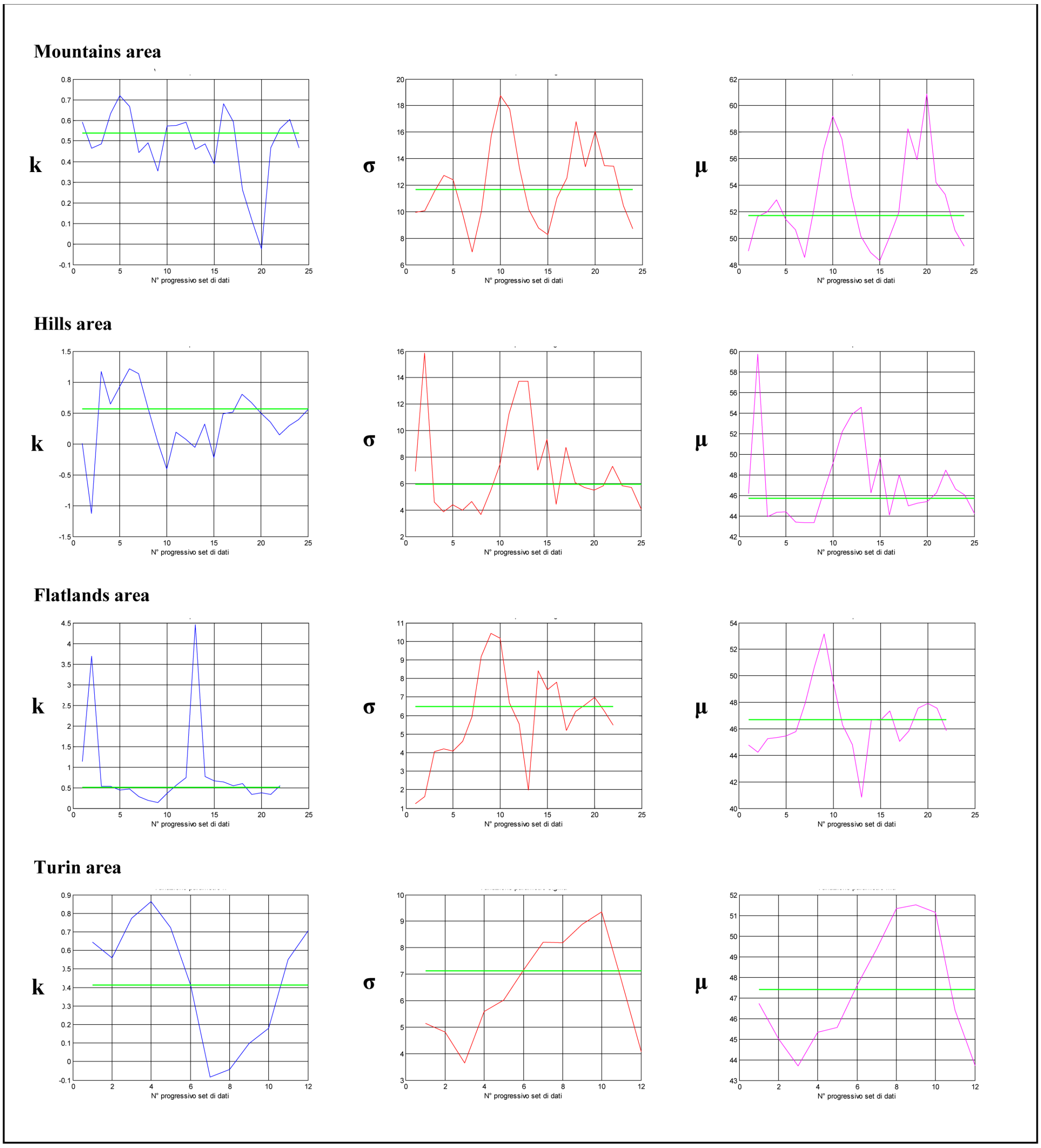

Figure 2. Variation of GEV distribution estimated parameters k, σ, μ for threshold T_1 = 40 mm/day, considering groups of 3 years in "running mode". In each of the 3 plots, x axis represents the progressive group of 3 years (according to **Table 6**).

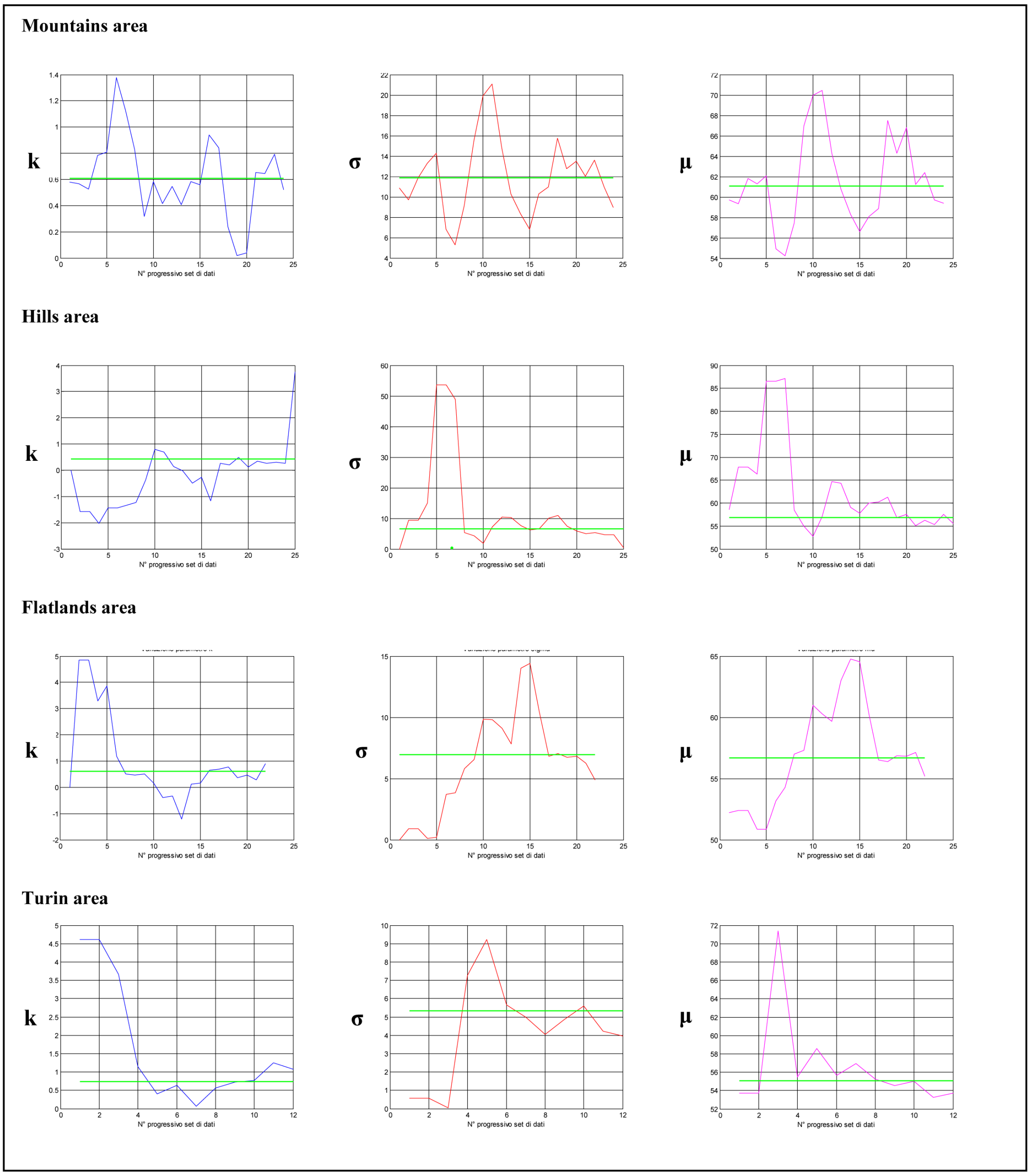

Figure 3. Variation of GEV distribution estimated parameters k, σ, μ for threshold T_2 = 50 mm/day, considering groups of 3 years in "running mode". In each of the 3 plots, x axis represents the progressive group of 3 years (according to **Table 7**).

are not significantly different for the 4 orographic regions examined (Mountain area, Hills, Flatlands, Town of Turin). However, even a relatively dense gauge network is not able to put in evidence "extremes" distribution changes over a short time interval correlated with climatic changes: a different approach should be considered.

In the near future, we intend to use meteorological radar data hoping to get more significant results for short time variations, possibly exploiting the high temporal and spatial resolution of a small X-band weather radar present in the area [17] [18].

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