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The Influence of Climate Change on Heavy Rainfalls in Central Italy

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Abstract

In recent years there is a growing concern by the community, scientific and not, about global warming and climate changes. The fact that the global temperature is growing up after the increase of the greenhouse gases emissions is already known, but there is still wondering about its effect on the hydrological cycle and most of all, on rainfalls. Many studies supported by the Intergovernmental Panel on Climate Change (IPCC) showed that there is a general increase of heavy rainfalls also in areas where total annual precipitation is not prominently changed. Changings about frequency, intensity, duration in rainfalls and in weather events in general are still objects of uncertainty and past studies referred to different regions do not give an unanimous answer about their trends. The Mediterranean area, which includes Italy, is supposed to be one of the most reactive to climate change and deep effects are expected. This paper deals with rainfall tendencies in the Umbria Region, Central Italy, since almost all the regional territory is included in the Upper Tiber River Basin and many areas are prone to risk of flooding. The climate in the Umbria region is different from zone to zone, in fact the weather is cold and wet in the East areas, near the Apennine Mountains and hotter and drier in the West, close to Tuscany region.
Because of this variability a lot of rain gauges were placed in the last 10-15 years. Nowadays a very dense rain gauge network is present (more than 90 rain gauges for a regional area of 8464.33 km^2, about one station each 90 km^2). The aim of this paper is to analyze if climate change affects rainfall intensity in Umbria. Three meteorological stations have been selected: Città di Castello, Todi and Orvieto. They provide the longest series of data and the best quality in rainfall measurements. Rainfall measurements began in the thirties and have gone on until nowadays even if there are some interruptions (most of all during the years of the Second World War). The analyses of heavy rainfalls of the three stations, and most of all the data referred to Todi, whose geographical position is barycentric in the regional territory; show that there are not considerable changes in rainfall maxima and intensities in the last seventy years.

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1. Introduction

The paper focuses on rainfall and their relationship with climate changes. Knowledge of rainfalls and of the way they act is really important for human activities. As rainfall has a direct influence on natural environment, there are economics implications due to water usage and management in the primary, civil and energetic sectors. Rainfall rates generate changes on the flow in the hydrographic network and their variations; in particular, the increase of extreme values represents additional risk for people who live in areas prone to flooding. These issues are also directly connected to water resources management, most of all with the presence of hydroelectric energy production structures and of reservoirs.

In recent years extreme events connected to rainfalls, like floods, droughts, cloud bursts and so on seem to happen more frequently than in the previous decades. So it's very important to understand when, where, and how these phenomena can occur, to plan human activities and design hydraulic and road infrastructures in the best and most safe way with the aim to realize buildings and to manage urban and countryside environment, minimizing damages due to heavy meteorological events.

Rainfall studies are based on measurement samples; the longer the series are, the better understanding on what happened in the past, what's happening in the present and what will happen in the future in a fixed area is possible. There are different methodology to measure rainfall rates: the use of raingauges with tipping-buckets represents the classical approach (Strangeways, 2004); radar can be also employed, but it's very expensive and in mountainous areas rainfall observations could be affected by errors related to complex orography (Borga et al., 2000); satellite measurements are adopted in basins and countries lacking of dense rain gauge network (Kidd et al., 2009).

Italy has an important historical role in the meteorological measurements, which began in the XVII century in Florence with the Cimento's Academy (Brunetti et al., 2006). Measurements about rainfall rates began at the end of the XIX century, the length of data series changes between different areas of the country. Heavy rainfall analyses start from annual maxima for different duration (usually 1, 3, 6, 12 and 24 hours), in recent years deeper attention was focused on rain fall durations of less than an hour due to the increase of destructive short events. Precipitation maxima evaluation is fundamental to forecast rainfall rates expected in a fixed area with a fixed return period (Intensity Duration Frequency -IDF- curves), which are essential to design flood control alternatives. In addition, droughts and floods diffusion, which are related to precipitation events are of interest.

In the last century, an increase of greenhouses gas emissions caused the growth of global surface and atmosphere temperatures, determining a major water-holding capacity of atmosphere, a faster and more substantial evaporation (Hidalgo-Muñoz et al., 2011) and a general quickening of hydrological processes. In the Fifth Assessment Report (AR5) of 2014, the International Panel on Climate Change published a series of phenomena which confirms the relationship between global warming and extreme events all over the world (Hartmann et al., 2013). In the period 1951-2003 precipitation maxima increased more than rainfall averages, most of all in the mid-latitude areas, even where total annual precipitation has been reducing. On the other hand, a reduction of this phenomena has been observed in some areas (Hartmann et al., 2013). Rainfall trend change from region to region and from season to season, even if areas with positive trends are more diffused than the ones with negative trends and the biggest variations are referred to wintertime. The regional variability of trends reported by the IPCC is confirmed by results of different papers. For example, Quirmbach et al. (2012) analysed precipitation data in North Rhine-Westphalia region and found that over the period 1950-2008 there were no significant trends in the number of extreme events each year. A similar study has been conducted by Hidalgo-Muñoz et al. (2011) in Andalusia (Spain) where an increase of extreme events in wintertime has been observed in the period 1955-2006. It's important to highlight that the IPCC studies refer to events with a duration equal or greater than 24 hours because of their diffused availability and that in the AR5 the necessity to extend rainfall analyses to events of shorter duration, whose growing influence on society and ecosystems has been recognized, is introduced as a goal. Sub-daily precipitation extremes are complex and different conclusions about their evolution in time have been suggested.

The aim of this work is to analyse maxima rainfall rates for different durations in the Umbria region, Central Italy, to evaluate if, during the last decades, climate changes influenced the pluviometric regime of this region and if extreme events are more frequent than in the past. Knowledge about metadata and rain gauge positions, during the years in which measurements are available, has been enhanced due to the fact that data variations may be caused not only by different rainfall intensity but also by other factors like relocation of rain gauges, growth of vegetation or realization of new buildings close to the instrumentation.

2. Case study

Heavy rainfalls have been analysed in the Umbria region, Central Italy, which extends over 8456 km^2 and has a quite continental climate because of the absence of a coast (see Figure 1).

Fig. 1. A general map of the Umbria Region.

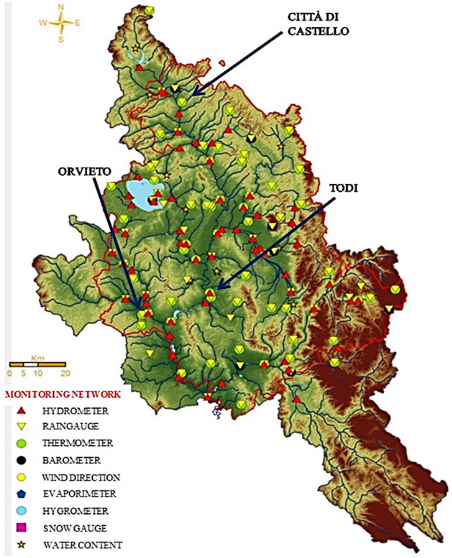

Fig. 2. Umbria Region Hydrological Monitoring Network.The position of the raingauge stations investigated in this paper has been indicated.

Table 1. Città di Castello rainfall annual maxima (in mm) for durations of 1, 3, 6, 12 and 24 hours.

Year	1h	3h	6h	12h	24h	Year	1h	3h	6h	12h	24h
1929	17.1	22.4	22.4	22.4	38.6	1971	14.0	25.8	30.2	43.2	48.2
1930	14.0	35.0	35.0	56.5	56.5	1992	35.5	61.3	67.7	72.6	74.7
1931	4.9	20.5	21.6	21.9	37.0	1993	36.7	42.5	43.6	44.3	44.8
1932	12.0	29.8	37.0	46.0	62.2	1994	34.8	35.4	36.5	50.4	65.0
1933	11.8	20.6	22.0	52.8	57.2	1995	24.1	26.7	32.4	44.1	62.8
1938	45.2	66.6	66.8	67.0	83.0	1996	20.6	30.4	52.7	73.7	78.9
1939	15.8	23.4	33.0	54.8	88.0	1997	17.8	30.9	35.8	55.9	79.8
1942	33.6	33.6	46.6	58.8	65.2	1998	21.4	29.6	31.2	36.1	54.7
1943	17.4	27.2	35.4	48.4	56.2	1999	27.3	28.6	34.4	40.1	43.7
1946	23.8	43.0	49.4	59.4	69.0	2000	22.1	33.2	37.7	51.9	74.8
1947	40.2	40.2	40.2	47.4	59.0	2001	23.2	25.8	45.9	49.9	50.5
1948	15.4	24.2	28.0	36.0	67.8	2002	20.7	26.8	29.2	38.8	51.5
1950	23.0	28.6	41.4	50.0	50.4	2003	23.1	28.6	30.5	32.0	43.5
1954	15.0	20.0	37.0	44.0	47.4	2004	27.0	27.1	27.2	30.2	48.7
1962	30.8	30.8	30.8	36.0	49.0	2005	26.8	35.1	39.1	50.2	77.7
1963	28.4	32.6	51.0	56.5	61.0	2006	22.1	33.5	46.4	65.4	83.1
1964	39.2	39.2	46.4	54.5	69.8	2007	18.7	24.3	29.8	31.1	39.0
1965	28.0	49.0	70.0	108.2	111.2	2008	23.6	24.0	29.4	42.4	62.0
1966	33.5	37.0	46.0	62.4	67.4	2009	25.1	25.5	25.9	26.5	38.1
1967	29.6	39.0	39.2	39.4	39.6	2010	28.1	31.1	51.3	70.0	73.4
1968	27.8	39.0	57.0	73.6	74.2	2011	21.4	29.5	37.3	38.7	40.4
1969	26.0	37.4	49.8	58.6	61.0	2012	31.2	32.4	35.7	65.3	119.6
1970	18.4	21.8	23.8	33.0	45.8	2013	25.2	31.8	46.1	68.8	93.5

Umbria's orography is complex along the North-Eastern and Eastern boards, where the Apennine Mountains are located, whose tops exceed 2000 m; the territory is typically hilly and flat in the inland valleys in Central and Western areas. Because of this orographic variability, the climate is different form zone to zone. On the highland areas in the East annual cumulative rainfall is in the range 900-1200 mm, while it is about 500-700 mm in the West zones, near Tuscany, where the influences of warm currents incoming from the Tyrrhenian Sea become significant. In the same way temperatures in the East are very low in winter and moderate in summer, while in the West they are generally higher with maximum of 30-35°C in the hottest periods, in particular in the inland valleys. Almost all the regional territory is included in the Tiber River Basin. In fact, the Tiber River crosses all the areas from North to South-West receiving water from many tributaries, which are more numerous on the hydrographic left side. tributaries , like Chiascio, Topino and Paglia. Rivers, have a flow rate strongly conditioned by rainfall, so heavy events generate warnings in towns and country sides prone to flooding, in particular the ones located in the Upper Tiber River Valley, Orvieto's zone, and in the Umbrian Valley.

Table 2. Todi rainfall annual maxima (in mm) for durations of 1, 3, 6, 12 and 24 hours.

Year	1h	3h	6h	12h	24h	Year	1h	3h	6h	12h	24h
1931	12.3	24.5	26.0	29.8	33.1	1984	23.0	27.0	38.6	54.0	67.0
1932	21.0	54.0	54.0	54.4	56.0	1985	16.4	24.0	24.0	27.0	43.4
1933	25.0	30.8	35.2	36.6	48.2	1986	22.0	27.0	40.0	69.0	98.6
1934	62.2	67.4	67.4	69.6	69.6	1987	44.8	47.2	47.2	50.8	62.6
1936	72.8	136.0	157.8	176.4	207.0	1988	22.6	32.4	36.0	54.6	60.0
1937	28.4	32.4	49.4	68.4	80.0	1989	22.0	42.0	45.2	45.8	45.8
1938	25.0	36.0	48.6	64.8	65.8	1990	24.0	43.8	59.4	61.8	65.2
1939	32.8	37.6	51.4	52.8	53.2	1991	19.8	20.0	23.0	34.4	46.8
1942	17.4	20.8	29.4	32.4	47.0	1992	18.4	31.4	40.3	50.5	50.8
1959	24.6	24.6	29.6	51.4	57.0	1993	19.2	24.4	35.9	67.1	84.1
1960	23.5	55.0	61.0	70.6	124	1994	23.8	24.9	25.3	29.4	38.8
1961	25.0	33.0	54.0	65.6	82.8	1995	64.7	95.3	135	135.7	137.5
1962	24.0	33.2	38.0	45.2	55.0	1996	23.2	25.0	25.4	35.5	47.2
1964	54.4	65.4	73.2	78.6	90.8	1997	35.7	47.3	88.4	106.2	118.2
1965	43.0	48.8	56.8	60.5	84.0	1998	20.8	39.9	60.1	64.3	98.9
1966	30.2	30.8	33.8	41.6	42.2	1999	31.1	41.0	46.6	67.9	88.2
1967	45.5	45.5	45.5	56.2	64.2	2000	28.4	38.0	40.0	40.2	42.2
1968	28.0	86.0	95.6	96.8	97.0	2001	38.1	45.3	45.7	54.6	54.6
1969	28.4	29.0	49.0	87.4	103.4	2002	32.3	36.4	46.1	75.1	83.1
1970	15.2	21.8	35.0	38.2	38.2	2004	29.3	35.9	37.2	38.1	47.4
1972	24.0	31.5	35.0	41.8	46.6	2005	41.0	41.7	43.4	44.6	70.6
1973	57.4	58.0	58.0	58.0	58.0	2006	18.0	21.1	27.2	34.9	41.1
1974	41.2	41.2	41.2	46.0	56.5	2007	22.7	27.6	30.8	35.1	36.8
1976	30.0	46.0	47.2	50.4	51.4	2008	47.8	48.2	50.1	50.3	55.6
1977	20.8	21.2	33.6	40.4	41.8	2009	22.7	23.0	41.2	52.7	83.3
1978	29.6	31.8	31.8	44.2	74.2	2010	19.8	22.5	33.2	50.8	65.1
1980	35.4	42.9	60.4	72.4	93.6	2011	18.6	24.3	28.1	32.2	37.5
1981	24.4	28.8	28.8	28.8	28.8	2012	21.4	33.3	42.8	54.6	67.5
1982	35.8	48.2	48.2	48.2	49.8	2013	19.7	29.1	37.4	44.4	45.8
1983	25.8	28.8	36.0	45.2	63.0						

A very dense rain gauge network is necessary properly describe these territorial climate and rainfall variations. In the last two decades, the Umbrian rainfall network has become denser: 18 rain gauges were installed in 1992 while they increased to 35 in 2001, to 59 in 2006 and 93 in 2013 (Figure 2). Not only the number of rain gauges increased, but also data quality improved. In fact, rainfall depth is observed, registered and communicated in real time to the Regional Monitoring Center minutely detailed, while in the past measurements were made each thirty minutes and stored by a registration station next to the gauge. With this reduced time of measuring rainfall maxima for each event (even shorter than an hour) can be obtained with very high accuracy.

However, this well-advanced rain gauge network has been working only for 10-20 years, a too short period to investigate if the last decades in the Umbria region show an increase of extreme events. In the studied area an important research in determining maximum intensity and short duration rainfalls has been carried out in 1992 by Regional Authorities using data from stations operative up to that year.

In this work, an analysis of heavy events has been based on data observed before and after 1992; only a few measurement stations could be investigated and three of them have been chosen: Città di Castello, Todi and Orvieto (see Figure 2). In fact, in these three places rainfalls have been recorded since thirties and rain gauges have never been relocated. Therefore, these rainfall series are longer than the other ones and there were no external changing factors influencing measurements. Moreover these three stations are placed in strategic points inland Umbria Region, quite far from each other, and representative of the regional climate complexity (Figure 2). Città di Castello is located in the Upper Tiber Valley, in the North of the region; Todi is on a very central position in the Middle Valley; Orvieto is on the South West, near Lazio Region, and not far from Corbara dam and the confluence of Paglia River into the Tiber. Areas around Orvieto have a high risk of flooding (the last one in 2012 with human and economic losses). In tables 1-3 annual maxima for duration of 1, 3, 6, 12 and 24 hours since 1929 to 2013 for each of the three selected rain gauges are shown. Several years without observations are present, mainly during the Second World War. A historical series length is 46 for Città di Castello, 59 for Todi and 53 for Orvieto.

Table 3. Orvieto rainfall annual maxima (in mm) for durations of 1, 3, 6, 12 and 24 hours.

Year	1h	3h	6h	12h	24h	Year	1h	3h	6h	12h	24h
1929	16.0	16.0	22.5	60.4	60.4	1978	13.2	19.2	27.6	34.6	57.8
1931	15.3	17.9	23.6	28.5	29.5	1981	42.2	42.2	42.2	42.2	44.4
1932	9.2	26.6	26.6	27.8	50.6	1982	33.0	33.0	33.0	40.0	52.6
1933	27.6	34.0	38.8	38.8	42.2	1983	16.8	21.2	36.0	59.4	59.4
1934	37.2	45.2	52.8	59.2	59.2	1984	17.4	22.6	22.6	28.6	38.4
1936	43.0	78.2	100.2	143.6	180.2	1985	13.0	13.0	20.0	35.0	45.8
1937	24.2	24.4	25.2	37.8	47.4	1986	14.4	21.8	34.0	66.0	88.8
1938	22.6	31.4	37.6	47.0	49.2	1987	24.8	33.0	47.4	59.0	79.6
1946	66.0	123.6	124.0	124.0	124.0	1988	26.6	49.2	52.6	53.0	53.0
1947	22.8	25.6	35.6	63.2	83.0	1989	34.4	53.0	64.0	68.4	85.2
1948	50.4	58.0	58.8	58.8	65.2	1990	17.6	25.8	42.4	56.6	64.0
1951	19.0	27.5	37.0	53.4	78.6	1991	31.0	54.8	68.2	72.4	90.4
1952	15.0	20.0	30.0	43.5	53.0	1993	23.6	51.6	92.4	118.6	137.8
1954	36.8	37.8	37.8	41.2	48.2	1999	46.6	76.0	89.2	91.0	91.0
1956	33.0	41.5	41.5	41.5	60.4	2002	31.2	34.0	51.8	81.6	91.4
1957	25.0	25.0	26.2	41.2	42.2	2003	19.8	24.8	31.2	36.0	50.6
1959	26.0	28.2	32.5	54.5	60.8	2004	38.2	69.4	95.4	102.0	102.6
1960	50.0	100.0	115.0	158.0	161.8	2005	58.4	61.0	61.0	61.0	67.4
1961	25.8	35.5	45.8	61.2	64.6	2006	24.0	32.2	38.4	51.0	59.4
1962	48.2	49.4	52.8	54.0	54.5	2007	15.6	21.0	37.4	42.0	43.2
1965	71.0	76.6	112.6	119	197.6	2008	26.6	28.8	47.8	68.0	96.2
1969	16.8	22.0	37.0	59.0	75.2	2009	33.8	37.0	50.2	63.2	112.2
1971	62.0	78.0	78.0	78.0	78.0	2010	67.6	91.0	107.0	113.6	115.0
1974	18.6	18.8	20.4	31.6	37.4	2011	31.4	39.4	61.2	63.8	65.8
1975	35.6	45.6	51.8	52.4	56.0	2012	25.8	35.8	63.0	98.2	147.4
1976	23.6	28.8	34.8	36.0	53.2	2013	31.6	33.8	33.8	35.0	51.2
1977	8.2	21.2	32.4	38.0	50.0						

3. Results and discussion

The aim of this work is to understand if heavy rainfalls are changing in intensity and frequency in the Umbria Region as a consequence of climate changes observed all over the world in last decades, in terms of temperature and increase of extreme events. In Umbria case, three rain gauges have been selected because they are characterized by a high quality of data series. Their data was used to calculate annual rainfall maxima averages for each station and selected durations over different time records: last ten years, last twenty years, last thirty years (when available) and finally all the years with recorded measurements. The results obtained for Città di Castello's rain gauge are shown in

Figure 3. There are no considerable variations in the averages passing from a fixed reference period to another one. Averages referred to the "last 10 years" period are lower than the other ones for short durations and became bigger for the duration of 24 hours; anyway variations are so reduced that it is possible to affirm that nowadays in the Città di Castello area the situation is the same of several decades ago in terms of heavy events.

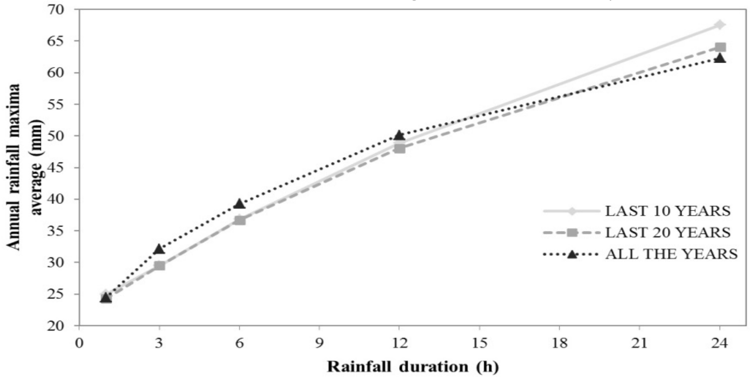

Fig. 3. Annual rainfall maxima averages for different durations and over different time periods for the Città di Castello data series.

Figure 4 shows Orvieto station results. Little changes happened in last decades, particularly for the longest durations: rainfall maxima averages generally increase in the most recent observation periods. As highlighted, remarkable differences are recorded most of all between "all the years" averages and "last 10 years" ones. They are quantified in 4,97 mm, 4,16 mm, 8,93 mm, 7,67 mm and 11,46 mm for duration of 1, 3, 6, 12 and 24 hours, respectively. Therefore it can be deduced that in the last years there was a little increase of maxima averages which rise with the event duration, until the value of 11,46 mm for 24 hours that is quite considerable.

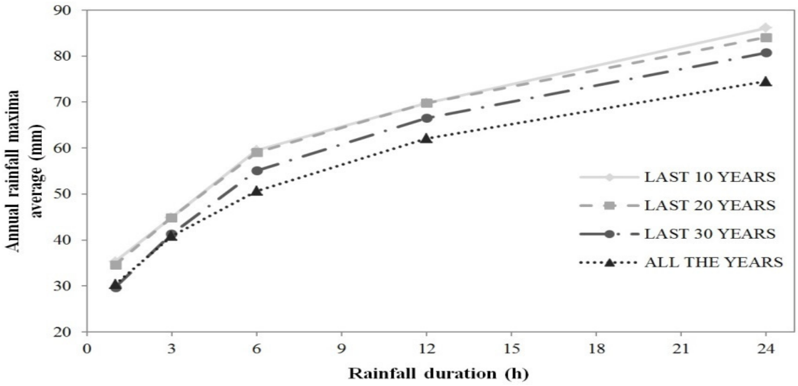

Fig. 4. Annual rainfall maxima averages for different durations and over different time periods for the Orvieto data series.

The third data series analysed is that of the Todi rain gauge with surprising results shown in Figure 5. In this case values calculated for the period of last ten years are quite lower than all the other ones (last twenty years, last 30 years and all the observation years), which are quite similar each other. "All the years-last 10 years" differences are of 3,64 mm, 8,48 mm, 10,05 mm, 12,40 mm and 11,81 mm for durations of 1, 3, 6, 12 and 24 hours, respectively, and it is clear that the trend for Todi's rain gauge is opposite in respect to Orvieto, even if the distance between the two rain gauge networks is only about 40 km. Therefore, these differences in observed data are prominently curious and lead to the conclusion that there is not a common trend in the area. Furthermore, the observed variations are generally low and probably caused by local factor like convective air motion or orography, certainly not by forcing agents related to climate changes.

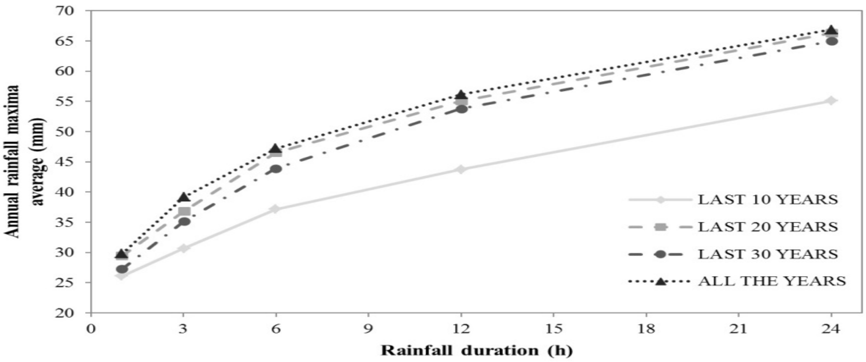

Fig. 5. Annual rainfall maxima averages for different durations and over different time periods for the Todi data series.

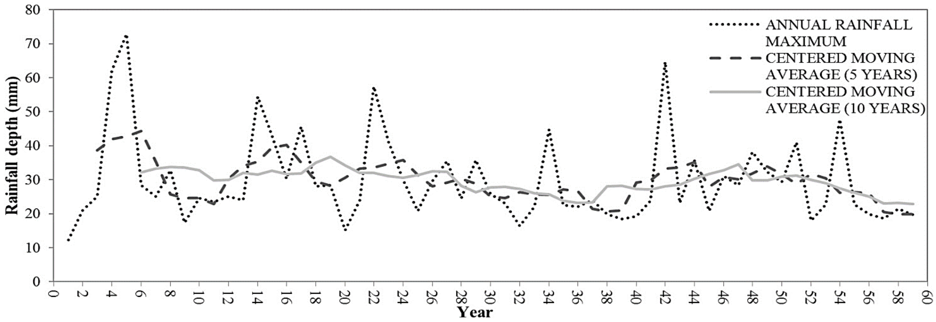

Fig. 6. Todi station annual rainfall maxima for a duration of a 1 h and Centred Moving Averages for a time period of 5 and 10 years. In the x-axis there are the years with available data, in crescent order, for the period 1931-2013.

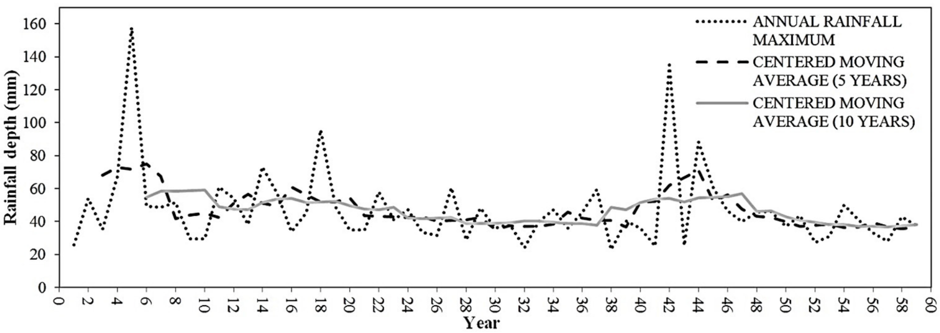

Fig. 7. Todi station annual rainfall maxima for a duration of a 6 h and Centred Moving Averages for a time period of 5 and 10 years. In the x-axis there are the years with available data, in crescent order, for the period 1931-2013.

The Todi rain gauges provides the best data series of the region because it has the widest temporal extension and the greatest number of measurements and it's also the station with the most unexpected results. For these reasons, further analyses on its rainfall data series were performed as shown in Figures 6-8, referring to rainfall data for duration of 1, 6 and 24 hours, respectively; the dotted line displays annual maxima for fixed duration, the dashed and solid ones point out Centred Moving Averages (CMA) of the same quantity for a time period of 5 and 10 years.

Centred Moving Averages were introduced because they dampen rainfall peaks and show trends with respect to annual maxima rainfall data. The analysis of the afore-mentioned figures highlights that there were no changes of heavy rainfalls in the period 1931-2013 for all the three durations because the Centred Moving Averages values are almost constant, without great fluctuations from the first years of the observed period to the last one. Two strong events were registered in 1936 and 1995 but they don't affect general rainfall trend because they are far away each other. From these initial analyses it seems that there is no evidence of changing about rainfall maxima in Umbria Region, unlike it's happening in others areas of Europe or of the World (Hartmann et al., 2013).

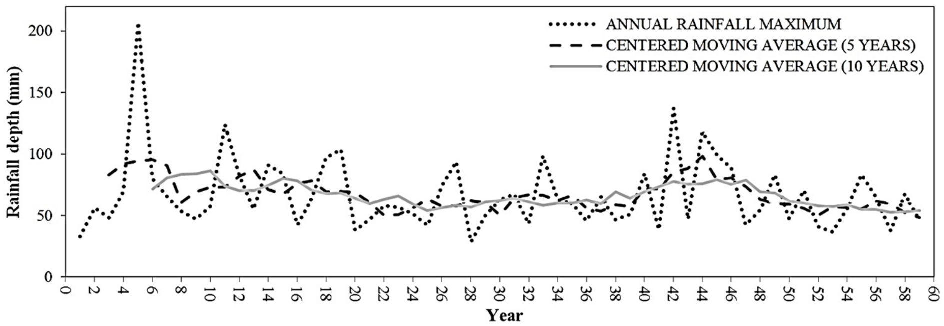

Fig. 8. Todi station annual rainfall maxima for a duration of a 24 h and Centred Moving Averages for a time period of 5 and 10 years. In the x-axis there are the years with available data, in crescent order, for the period 1931-2013.

4. Conclusions

The increase of greenhouse emissions in the last century caused a higher global average temperature and climate changes are happening all over the world. In fact it seems that extreme events like droughts, hurricanes, heavy rainfalls, blizzards, sea storms and so on are more frequent. The fifth IPCC report of 2014 shows that in a global view there is a lot of evidence showing a relationship between human activities and global warming. International Authorities should take actions to mitigate phenomena dependent on it. Contrasting results were found about heavy rainfalls in different areas of the world, so it is interesting to investigate what happened during the last decades in the Umbria Region, Central Italy. The study area is covered by a very efficient monitoring network with more than 90 rain gauges, but only few of them provide data series long enough to allow researchers to investigate rainfall trends for wide periods. Three rain gauges station (Città di Castello, Todi and Orvieto) were selected and annual rainfall maxima were obtained for event durations of 1, 3, 6, 12 and 24 hours together with their averages calculated over periods less and less recent (last 10 years, last 20 years, etc.). These averages were compared for each station. Città di Castello maxima are almost constant for all the intervals, except the last 10 years, where rainfall maxima values are lower than for the Todi station and greater than for Orvieto . This observed disagreement and other analyses carried out using Central Moving Averages shows that there is no clear trend in all the observation periods. Finally, it can be concluded that rainfalls in Central Italy do not seem influenced by climatic forcing related to climate changes, because their recent trend is similar to that of 50-70 years ago.

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