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Detection of variations in precipitation at different time scales of twentieth century at three locations of Italy

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ABSTRACT

In continuation of efforts to contribute to the studies on climatic change, 120 years time series precipitation of Firenze, Pisa and Palermo of Italy was analyzed over two time scales (10 and 60 years). Within the long (60 years) time scale, patterns of annual, seasonal, and monthly precipitation were studied. Mean annual precipitation decreased by 50, 148 and 84 mm, and annual rainy days decreased by 8, 12 and 3 days respectively, at Firenze, Pisa and Palermo in 2nd half than in 1st half of the century. Precipitation in spring season at Firenze and Pisa and in winter at Palermo showed highly significant decline in 2nd half of the century compared to the 1st half. Decline in rainy days was also higher in spring season (by 4 days per year) at Firenze and Pisa and in winter (by 3 days per year) at Palermo in 2nd half of the century. Monthly precipitation means in 2nd half, however, depicted increase of precipitation across all the three locations (non-significant) only in August and September. Long-term (120 years) trend over 20th century reveals highly significant negative trend in rainy days at Firenze and Pisa and in precipitation at Pisa and Palermo. Most interesting observation from this study is the highly significant increase in the days with low ($<$ 1 mm) precipitation at all the locations and decrease of days of frequently occurring precipitation amounts (5 to 15 mm) by 4 and 6 days per year at Pisa and Palermo, in the later half than in 1st half. Long-term standardized precipitation indices depicted downward trend in precipitation and increase in dry years with longer duration and higher intensity in the later half at all three locations. Decline in the precipitation and rainy days, increased precipitation extremes and intensities noticed in this study are similar to the globally observed signals of Green House Gases induced climate change.

1. Introduction

Global climate change due to anthropogenic pollution of the atmosphere became a high profile global issue after the acceptance of Kyoto protocol by United Nations Framework Convention on Climate Change (UNFCC) in the year 1997. Though surface air temperature has been the most widely used indicator of global climate change, surface precipitation is equally important component of changing global climate (Hulme, 1995). Understanding the changes of precipitation pattern is all the more important in view of its greater impact on agriculture in general and rainfed agriculture in particular. The changes in annual precipitation during the present century were studied at both global (Hulme, 1995; Houghton et al., 1996; Dai et al., 1997) and at regional levels (Forland et al., 1997; Hanssen-Bauer et al., 1997; Thompson, 1999; Brunetti et al., 2006; Trenberth et al., 2007; Toreti et al., 2009). Detection of changes in precipitation is accomplished through analysis of both long-term measured precipitation data as well as precipitation data simulated by general circulation models (Gregory and Mitchell, 1995; Kattenberg et al., 1996; Coppola and Giorgi, 2010). Parry (Parry, 1985) highlighted the importance of reliable estimates of possible regional changes in climate due to increase of CO_2 for determining the likely impacts on agriculture. Realising the importance of regional level climate changes, many studies on changes in precipitation due to climate change were made at regional or country levels (Karl et al., 1996; Forland et al., 1997; Lucero and Rodriquez, 1999; Thompson, 1999; Brunetti et al., 2004) using historical time series data. For making impact studies, information on variability of precipitation at shorter time scales, within a given region will have added advantage. The extreme climatic events, which are essentially, short time scale variations

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Fig. 1. Geographical locations of Firenze, Pisa and Palermo.

having profound impact on agriculture, have received attention only in last few years. Lack of high quality long-term climate data was identified as the major obstacle for quantifying the changes in extreme events over 20th century (Easterling et al., 1999). An attempt has been made here to understand the changes in precipitation and precipitation extremes at short and long time scales of the 20th century at three locations of Italy. Additional objective is to compare the precipitation changes at Firenze with the precipitation changes at a nearby (Pisa) and faraway (Palermo) locations.

2. Material and methods

Fig. 1 shows the geographical locations of Firenze, Pisa and Palermo whose time series of precipitation were analyzed in this article. The latitude, longitude and elevations of Firenze, Pisa and Palermo, respectively are: 43° 46′ N, 11° 15′ E, 74.4 m; 43° 68′ N, 10° 38′ E, 2 m and 38° 6′ N, 13° 21′ E, 71 m above mean sea level. Firenze and Pisa are located to the southwest of the Apennine Mountain range in central part and Palermo in the southern part of Italy. The distance between Firenze and Pisa is 80 km while Palermo is 650 km away from Firenze. The time series of precipitation for 120 years spanning from 1889 to 2008 of all these three locations were used in this study.

2.1. Metadata of meteorological stations

The meteorological observatory of Firenze is at Ximeniano in the centre of Firenze city. The observatory is established on the terrace of a building. This observatory was shifted to here from its previous location as per the recommendations of WMO, Geneva in 1948. The daily observation timings of 9, 15 and 21 h during the period 1879–1941 were changed to 8, 14 and 19 h afterwards.

The meteorological station of Pisa is located in the garden of the Faculty of Agriculture of the University of Pisa. This station was moved 100 m far in 2001 in another garden. The daily values were obtained adding cumulative observations taken three times a day.

The meteorological station of Palermo is located at the Astronomic Observatory since the 1791. The precipitation observations were made several times during the day with a frequency that changed from 1 to 8 times a day. For about 100 years (1851–1950), the same instrument was used to observe precipitation.

In all the three stations starting since the nineties, the mechanic instrumentations were replaced with electronic ones.

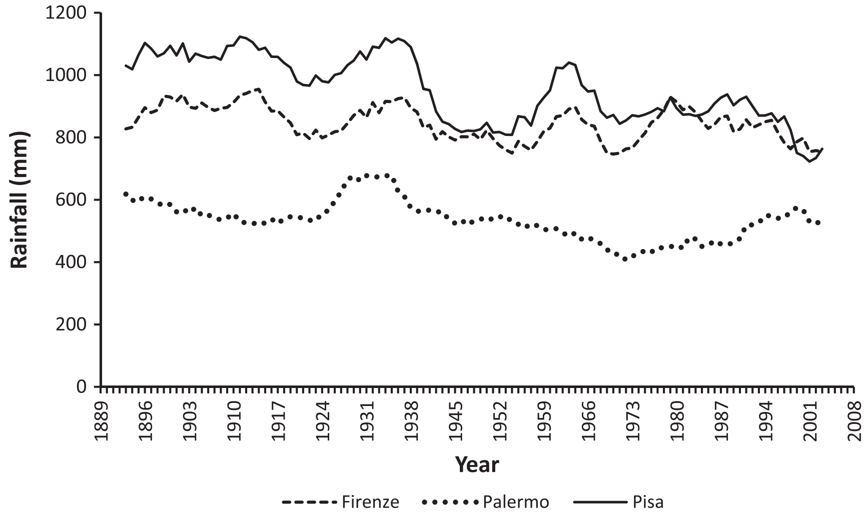

Fig. 2. Gaussian filters of precipitation at Firenze, Pisa and Palermo of Italy.

2.2. Calculation of totals

2.2.1. Annual

Annual means of precipitation were worked out by summing the precipitation over 365 days of each year, thus generating 120 time series values of annual precipitation at each of the location.

2.2.2. Seasonal

As it is an established practice to analyze precipitation of meteorological seasons, in this paper seasonal precipitation of all the four seasons of Italy were analyzed. These seasons are (i) Winter (December to February), (ii) Spring (March to May), (iii) Summer (June to August), (iv) Autumn (September to November). Seasonal totals of precipitation were calculated by summing the precipitation over the total days of each season. Thus, 120 time series precipitation for each of the 4 seasons of a year (120×4) were generated.

2.2.3. Monthly

Monthly precipitation values of each month in each year of the series were worked out by summing the precipitation of all the days of that month in that year. Thus, 120 time series for each of the calendar months of a year (120×12) were generated.

2.3. Special indices

2.3.1. Standardized precipitation index (SPI)

SPI developed by McKee et al. McKee et al. (1993, 1995) was used for analyzing drought years in different time periods of the time series precipitation of all three locations. Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals of locations. The data is then transformed into a standardized normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). The SPI in this work was calculated by using the SPI program (SPI_SL_6.exe) developed by National Drought Mitigation Centre, University of Nebraska, USA (W.M.O., 2012).

2.4. Statistical methods

2.4.1. Homogeneity test

Homogeneity tests could not be performed on the time series of all these three locations, *viz*., Firenze, Pisa and Palermo, due to lack of availability of reference data series for them.

2.4.2. Student's t-test and regressions

The t-test (Hald, 1952) assesses whether the means of two groups are not statistically different from each other (null hypothesis H_0: $\mu_1 = \mu_2$). This test with unequal variance was used to see whether precipitation means of two different time scales are statistically significant or not. Linear regressions of precipitation (annual and seasonal), rainy days and precipitation intensity (ratio of precipitation and rainy days) against years were made to determine trends (slopes) of these parameters over the years. The *P*-values and F statistics on slopes and regressions were used to test whether the observed changes were significantly different from zero ($P < 0.05$). All these tests available in excel package of Microsoft 2000 were utilized for the data analysis.

2.4.3. Urbanization effect

The effect of urbanization on the precipitation data of the three stations were studied by fitting correlation between precipitation and city population series of 120 years. The correlation coefficients obtained between annual precipitation and population are −0.39 (Pisa), −0.13 (Firenze) and −0.35 (Palermo), which are not statistically significant. From the analysis, it was understood that urbanization, as a function of population growth has no effect on precipitation. Other urbanization factors like canyon geometry and air pollution may have some effect on precipitation. But due to lack of data on these parameters, effect of them on precipitation was not attempted.

2.4.4. Autocorrelation and Gaussian filter

The annual precipitation series of Firenze, Pisa and Palermo showed lower correlations of 0.04, 0.19 and 0.19 at lag-1 thus indicating randomness in data series. To know any regularity present in the low frequency mode fluctuations, time series of precipitation of Firenze, Pisa and Palermo were smoothed by applying 9-point Gaussian low-pass filter with truncated end points (W.M.O., 1966). The 120 years time series of precipitation of three locations along with their 10-year Gaussian filters (Fig. 2) showed no distinct increasing or decreasing trend but showed oscillations at shorter scales. Hence, short time scale fluctuations at 10-year period in the time series of precipitation were studied. Like in the previous article (Vijaya Kumar et al., 2005), total period of 120 years (1889–2008) is treated as a century and this period is referred as last century or 20th century. In short time scale, total precipitation series has been divided into twelve 10-year periods. Similarly, in the long time scale, the periods 1889–1948 and 1949–2008 are referred as first and second halves of the century.

3. Results and discussion

Before analyzing long and short-term changes in precipitation at all three locations, attempt was made to relate precipitation series of Firenze with precipitation series of nearby (Pisa) and far away (Palermo) locations. The correlation coefficient between precipitation of Firenze and Pisa was highly significant ($r=0.66$) and that of Firenze and Palermo was non-significant ($r=0.09$). Though these relations are indicating the spatial variability in precipitation, some similar features are also observed in these three precipitation series, which are discussed in following sections.

3.1. Mean annual precipitation

Annual precipitation means of three locations calculated over 10-year averaging periods (time scales) of the 20th century (Fig. 3) showed that precipitation means are highly fluctuating in successive decades. Fluctuations at decadal and inter decadal time scales are most common and universal phenomena in time series of precipitation and atmospheric variables (Karl, 1988; Hu et al., 1998; Lucero and Rodriquez, 1999; Thompson, 1999). Half century (60 years) means of annual precipitation at Firenze, Pisa and Palermo showed significant reduction (at 1 and 5% P-level) of 50, 148 and 84 mm, respectively, in second half compared to its first half. These reductions amount to 5.8%, 14.5% and 14.5%, respectively at Firenze, Pisa and Palermo. This observation of declining precipitation is similar to the results reported by Parry (2000) that in some parts of southern Europe, annual precipitation decreased by 20% in the 20th century.

3.2. Seasonal precipitation

Under most circumstances, changes in seasonal precipitation distribution and intensities would matter more for arable crops than changes in annual precipitation (Rotter and Van De Geijn, 1999). Hence, changes in the seasonal distribution of precipitation were analyzed at all time scales.

3.2.1. Long time scale (60 years)

The seasonal means of precipitation in all the four seasons of a year during first and second halves of the century at all the locations (Table 1) depicted non-significant decrease in precipitation of any of the seasons across all three locations during the 2nd half of 20th century compared to the 1st half. Precipitation in the winter season (December–February) showed significant decline in 2nd half compared to 1st half only at Pisa and Palermo. The declining trend in precipitation of winter, though in contrast with the projections of increased precipitation in winter in northern hemisphere (Dai et al., 1997; Serreze et al., 2000), agrees with the results of declining precipitation in cooler season (January–March) reported for neighboring country, Spain (Sumner et al., 2001). In spring season, precipitation showed highly significant decline in 2nd half compared to 1st half at Firenze and Pisa. The significant decrease in annual precipitation during 2nd half of the century compared to its 1st half seems to be the result of declining precipitation of winter and spring seasons of the year at all three locations.

3.3. Monthly precipitation

3.3.1. Long time scale (60 years)

Mean monthly precipitation of all the 12 calendar months of a year in both halves of the 20th century (Table 2) at Firenze, Pisa and Palermo showed that all the months of the year, except August and September at Pisa; February, July, August, September and November at Firenze; and April, August and September at Palermo received lesser precipitation in the 2nd half of the century compared to its 1st half. However, decline in precipitation was statistically significant ($P \leq 0.05$) in three months (March, May and October) at Firenze, in five months (March, May, June, July and October) at Pisa and four months (January, February, November and December) at Palermo. Though, August and September received increase in precipitation in 2nd half over 1st half of century at all the three locations, it was significant ($P=0.07$) only in August at Firenze. At Palermo, the three winter months *i.e.*, December, January and February witnessed highly significant decline in precipitation in the present 60-years period compared to the previous 60-years period.

3.4. Rainy days

The temporal changes of rainy days over a longer period are good indicators of climate change. Realizing the importance of the changes in number of rainy days, Karl et al. (1996) used number of measurable precipitation days as one of the indices of the climate change.

3.4.1. Annual and seasonal changes

3.4.1.1. Long time scale. The total rainy days, *i.e.*, days receiving more than or equal to 1 mm of precipitation (W.M.O., 1981) in all the four seasons as well as in an year of 1st and 2nd halves of the 20th century at all three locations (Table 3) revealed that there

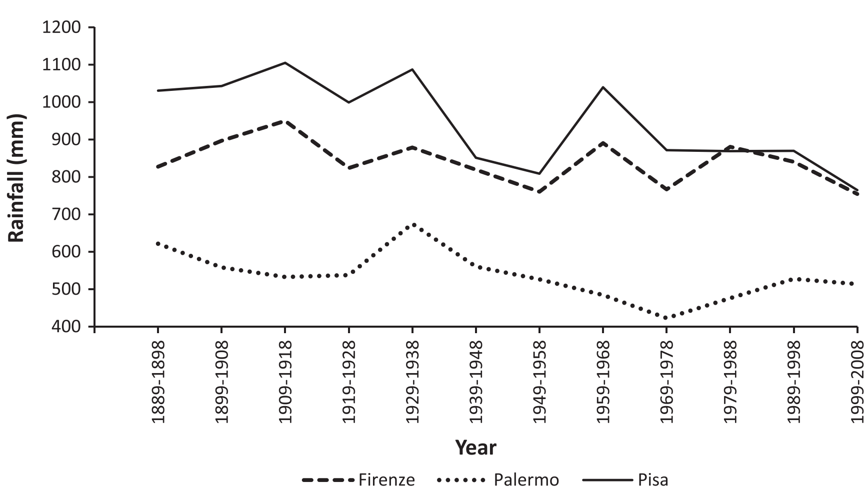

Fig. 3. Variability of precipitation at shorter time scale (Decades) at three locations of Italy.

was significant decline in the number of rainy days in all the seasons, during the 2nd half over the 1st half at Pisa only. However, significant decline in rainy days is confined to spring and autumn at Firenze and winter only at Palermo. Decreasing trend is reflected in annual rainy days also and rainy days per year declined by 8, 12 and 3 days at Firenze, Pisa and Palermo, respectively in the 2nd half compared to 1st half. The difference in annual rainy days between the two halves is highly significant (P=0.001) at all the locations except Palermo. Decrease in rainy days has also been noticed in northern Italy (Brunetti et al., 2000). Though the decline in rainy days is apparent in all the four seasons of the year at Firenze and Pisa, it is highly significant in spring (March–May) with a decline of 4 days per year in the 2nd half compared to 1st half at both the locations. The decrease in rainy days of autumn season, the main rainy season of Firenze and Pisa is also significant. At Palermo, winter, the main rainy season witnessed significant decline of 3 days per year in 2nd half compared to 1st half.

3.5. *Trends in precipitation and rainy days*

3.5.1. *Annual*

The long (120 years) time series of annual precipitation (RF), rainy days (RD) and their ratio (RF/RD) or precipitation intensity were analyzed for observing their trends in the 20th century. Among these three parameters, rainy days and precipitation at all three locations showed decreasing trend over the 20th century (Table 4). However, the decreasing trend of precipitation is significant at Pisa and Palermo, while that of rainy days was significant at Firenze and Pisa. The decreasing trend of rainy days is in line with the observation of Brunetti et al. (2001) reporting decreasing trend of rainy days in all regions of Italy. The precipitation intensity has not shown significant ($P<$ 0.05) and uniform increasing or decreasing trend across three locations. The trend of precipitation intensity was positive at Firenze in the central and negative at Palermo in the Southern Italy. The increasing trend of precipitation intensity at Firenze is similar to the observation of increasing precipitation intensity in northeastern Italy by Brunetti et al. (2001) while the negative trend in precipitation intensity at Palermo is contrary to the cited study.

Table 1
Seasonal and annual means of precipitation at long (60-years) time scale.

Location/Period	Winter (December–February)	Spring (March–May)	Summer (June–August)	Autumn (September–November)	Annual
Firenze					
1889–1948	209.3	223.4	140.4	292.9	866
1949–2008	201.7	192.1	142.6	279.2	816 (5.8)*
Significant at P-level	NS	0.01	NS	NS	0.04
Pisa					
1889–1948	264.2	245.2	139.9	370.0	1019
1949–2008	231.4	188.4	110.5	340.4	871 (14.5)
Significant at P-level	0.03	< 0.001	0.02	NS	< 0.001
Palermo					
1889–1948	239.4	111.4	27.0	200.0	578
1949–2008	176.1	108.8	28.6	180.6	494 (14.5)
Significant at P-level	< 0.001	NS	NS	0.08	< 0.001

* Values in the parenthesis are percentage of reduction in precipitation compared to the previous half.

3.5.2. *Seasonal*

The long-term (120 years) time series of seasonal precipitation could show highly significant decreasing trend of −4.9 mm per decade in spring season only at Firenze (Table 5). However, precipitation during all the seasons except autumn could establish highly significant decreasing trend at Pisa. At Palermo precipitation in winter only showed significant decreasing trend of −7.1 mm per decade. The decreasing trend of precipitation in winter is similar to the observation of Caloiero et al. (2011) in which decreasing trend of precipitation in autumn to winter is reported in southern Italy. All the three locations showed non-significant decreasing trend in precipitation of autumn season (September–November).

3.6. *Rainy days above threshold amounts*

Distribution of rainy days exceeding various threshold precipitation amounts in both halves of the century at all three locations (Table 6) showed that days with heavy rain (>100 mm) are increasing in the later half of the century compared to the former at Firenze and Pisa and decreasing at Palermo. The distribution of precipitation events showed that rainy days with more than 100 mm is a rarely occurring event in the long time series of 120 years at all the three locations, which is true for extra tropics where heavy rains usually constitutes significantly smaller fraction of precipitation events. The numbers of rainy days with 50–100 mm precipitation have not shown any significant increase or decrease in 2nd half compared to the 1st half at any of the locations. The assumption of >100 mm and 50–100 mm precipitation events as high precipitation extremes is in line with Karl and Knight (1998), in which precipitation greater than 50 mm per day were taken as extreme precipitation events. Another

Table 2
Changes in monthly precipitation over two halves of 20th century at three locations of Italy.

Location/Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Firenze												
1889–1948	64.4	61.9	74.1	71.8	77.4	62.8	34.5	43.1	73.3	114.0	105.6	83.0
1949–2008	59.0	64.1	58.1	69.8	64.2	53.1	36.2	53.3	76.3	93.3	109.7	78.6
Significant at P-level	NS	NS	0.03	NS	0.04	0.07	NS	0.07	NS	0.05	NS	NS
Pisa												
1889–1948	87.6	73.5	90.7	81.5	73.0	65.7	32.4	41.9	85.2	151.7	133.1	103.2
1949–2008	75.0	63.5	61.2	69.9	57.4	39.3	20.9	50.3	95.9	124.4	120.1	92.9
Significant at P-level	0.08	NS	0.001	0.09	0.02	0.001	0.03	NS	NS	0.05	NS	NS
Palermo												
1889–1948	77.6	67.1	48.2	38.5	24.7	10.3	5.1	11.6	36.5	80.5	83.1	94.8
1949–2008	61.8	48.2	47.6	41.3	19.9	7.8	3.8	17.0	43.2	71.8	65.5	66.1
Significant at P-level	0.01	0.001	NS	NS	0.09	NS	NS	NS	NS	NS	0.01	0.001

Table 3
Mean seasonal and annual rainy days across different time scales of the century.

Location/Period	Winter	Spring	Summer	Autumn	Annual
Firenze					
1889–1948	1515 (25.3)*	1635 (27.3)	830 (13.8)	1549 (25.8)	5529 (92.2)
1949–2008	1429 (23.8)	1405 (23.4)	801 (13.4)	1410 (23.5)	5045 (84.1)
t-test (*P*-level)	1.10 (NS)	3.25 (0.001)	0.58 (NS)	1.73 (0.04)	3.49 (< 0.001)
Pisa					
1889–1948	1598 (26.6)	1542 (25.7)	702 (11.7)	1656 (27.6)	5498 (91.6)
1949–2008	1459 (24.3)	1279 (21.3)	623 (10.4)	1412 (23.5)	4773 (79.6)
t-test (*P*-level)	1.76 (0.04)	3.57 (< 0.001)	1.67 (0.05)	3.00 (0.001)	4.49 (< 0.001)
Palermo					
1889–1948	1827 (30.5)	1010 (16.8)	206 (3.4)	1256 (20.9)	4299 (71.7)
1949–2008	1674 (27.9)	1023 (17.1)	224 (3.7)	1231 (20.5)	4152 (69.2)
t-test (*P*-level)	1.79 (0.04)	−0.19 (NS)	−0.64 (NS)	0.38 (NS)	0.97 (NS)

* Values in the parenthesis are days per year.

Table 4
Trends of annual precipitation, rainy days and precipitation intensity at three locations of Italy.

Climatic Variable	Firenze	Pisa	Palermo
Precipitation (mm/year)	−0.74 (NS)	−2.4 (R^2=0.13, $P<0.001$)	−1.0 (R^2=0.08, $P<0.001$)
Rainy days (days/year)	−0.13 (R^2=0.11, $P<0.001$)	−0.28 (R^2=0.19, $P<0.001$)	−0.06 (R^2=0.02, P=0.10)
Precipitation intensity (mm/day/year)	0.01 (R^2=0.03, P=0.07)	0.001 (NS)	−0.01 (R^2=0.03, P=0.06)

Table 5
Trend of seasonal precipitation (mm/year) at three locations of Italy.

Season	Period	Firenze	Pisa	Palermo
Winter	December–February	−0.16 (NS)	−0.61 (P=0.01)	−0.71 ($P<0.001$)
Spring	March–May	−0.49 (P=0.01)	−0.76 ($P<0.001$)	−0.10 (NS)
Summer	June–August	0.02 (NS)	−0.55 (P=0.01)	0.05 (NS)
Autumn	September–November	−0.11 (NS)	−0.51 (NS)	− 0.27 (NS)

Table 6
Distribution of rainy days exceeding various threshold precipitation amounts in first and second halves of the 20th century.

Location/Period	mm							
	> 100	50–100	25–50	15–25	5–15	2.5–5	1–2.5	0–1
Firenze								
1889–1948	1 (0.02)*	44 (0.7)	351 (5.9)	663 (11.1)	1970 (32.8)	1144 (19.2)	1110 (18.5)	1184 (19.7)
1949–2008	4 (0.10)	52 (0.9)	336 (5.6)	550 (9.2)	1864 (31.9)	1020 (17.0)	1008 (16.8)	1547 (25.8)
t-test (*P*-level)	−1.37 (0.09)	−0.76 (NS)	0.52 (NS)	3.08 (0.001)	1.54 (0.06)	2.28 (0.01)	1.95 (0.03)	−4.91 (< 0.001)
Pisa								
1889–1948	8 (0.1)	84 (1.4)	493 (8.2)	710 (11.8)	1925 (32.1)	1041 (17.4)	1048 (17.5)	1404 (23.4)
1949–2008	13 (0.2)	77 (1.3)	369 (6.2)	626 (10.4)	1675 (27.9)	932 (15.5)	902 (15.0)	1843 (30.7)
t-test (*P*-level)	−1.13 (NS)	0.51 (NS)	3.64 (< 0.001)	2.14 (0.02)	3.44 (< 0.001)	2.11 (0.02)	2.86 (0.002)	−4.71 (< 0.001)
Palermo								
1889–1948	2 (0.03)	36 (0.6)	175 (2.9)	353 (5.9)	1628 (27.1)	763 (12.7)	1275 (21.3)	1350 (22.5)
1949–2008	0 (0)	30 (0.5)	136 (2.3)	288 (4.8)	1266 (21.1)	1068 (17.8)	1192 (19.9)	1866 (31.1)
t-test (*P*-level)	1.43 (0.08)	0.66 (NS)	2.03 (0.03)	2.65 (0.005)	6.22 (< 0.001)	−4.50 (< 0.001)	0.82 (NS)	−4.45 (< 0.001)

* Values in the parenthesis are days per year.

interesting feature is that, the lower precipitation events (< 1 mm) called drizzle or light rains are showing significant increasing trends (6, 7 and 9 days per year at Firenze, Pisa and Palermo, respectively) in 2nd half compared to 1st half. Precipitation events in the categories 2.5 to 5, 5 to 15, and 15 to 25 mm are showing significant declining trend in later half compared to the earlier half at all three locations. It is a matter of grave concern that rainy days with precipitation of 5 to 15 mm, which are frequently occurring phenomena in all three locations, are declining by 1, 3 and 6 days per year at Firenze, Pisa and Palermo, respectively, in the later half compared to the first half. The decrease in the rainy days of all precipitation intensities and increase in the days with both highest precipitation (at two locations) and lowest precipitation (at all three locations) definitely indicates signals of climate change. Though increases in high precipitation events or contribution from high precipitation class intervals is reported earlier (Brunetti et al., 2001), increase in lowest precipitation events is a new finding.

Table 7
Number of days with heavy precipitation ($\geq$ 50 mm) in four seasons of the year and their changes over two halves of the century.

Location/Period	Winter	Spring	Summer	Autumn
Firenze				
1889–1948	5	4	6	31
1949–2008	7	6	10	34
t-test (*P*-level)	−0.56 (NS)	−0.66 (NS)	−1.00 (NS)	−0.33 (NS)
Pisa				
1889–1948	10	12	19	53
1949–2008	7	6	13	68
t-test (*P*-level)	0.69 (NS)	1.44 (0.08)	0.98 (NS)	−1.26 (0.10)
Palermo				
1889–1948	12	1	3	22
1949–2008	6	5	3	17
t-test (*P*-level)	1.07 (NS)	−1.68 (0.05)	0 (NS)	0.71 (NS)

3.7. *Heavy precipitation days in different seasons*

At Firenze, though number of rainy days with heavy precipitation ($>$50 mm) increased in all seasons of a year in 2nd half compared to 1st half of the century, the increase is not significant in any of the four seasons (Table 7). At Pisa, heavy precipitation days of 50 mm or above showed significant ($P=0.08$) decrease in spring season and significant ($P=0.10$) increase in autumn. At Palermo, heavy precipitation could show significant ($P=0.05$) increase in spring only.

3.8. *Standardized precipitation index (SPI)*

The plot of SPI values in individual years of the long time series of 120 years at three locations (Fig. 4) is depicting downward trend over the century. The moving average (smoothened curve) values of SPI over the century show alternative wet and dry cycles of years. Close observation of amplitude and width of the curves in early and late half-century reveals that intensities and duration of dry years were less in earlier half compared to the later half.

Number of years with more than or less than the threshold SPI values (Table 8) also revealed decreasing trend of precipitation and increasing trend of drought (SPI $<$ 0) years significantly ($P<0.01$) in 2nd half compared to the early half of 20th century at all

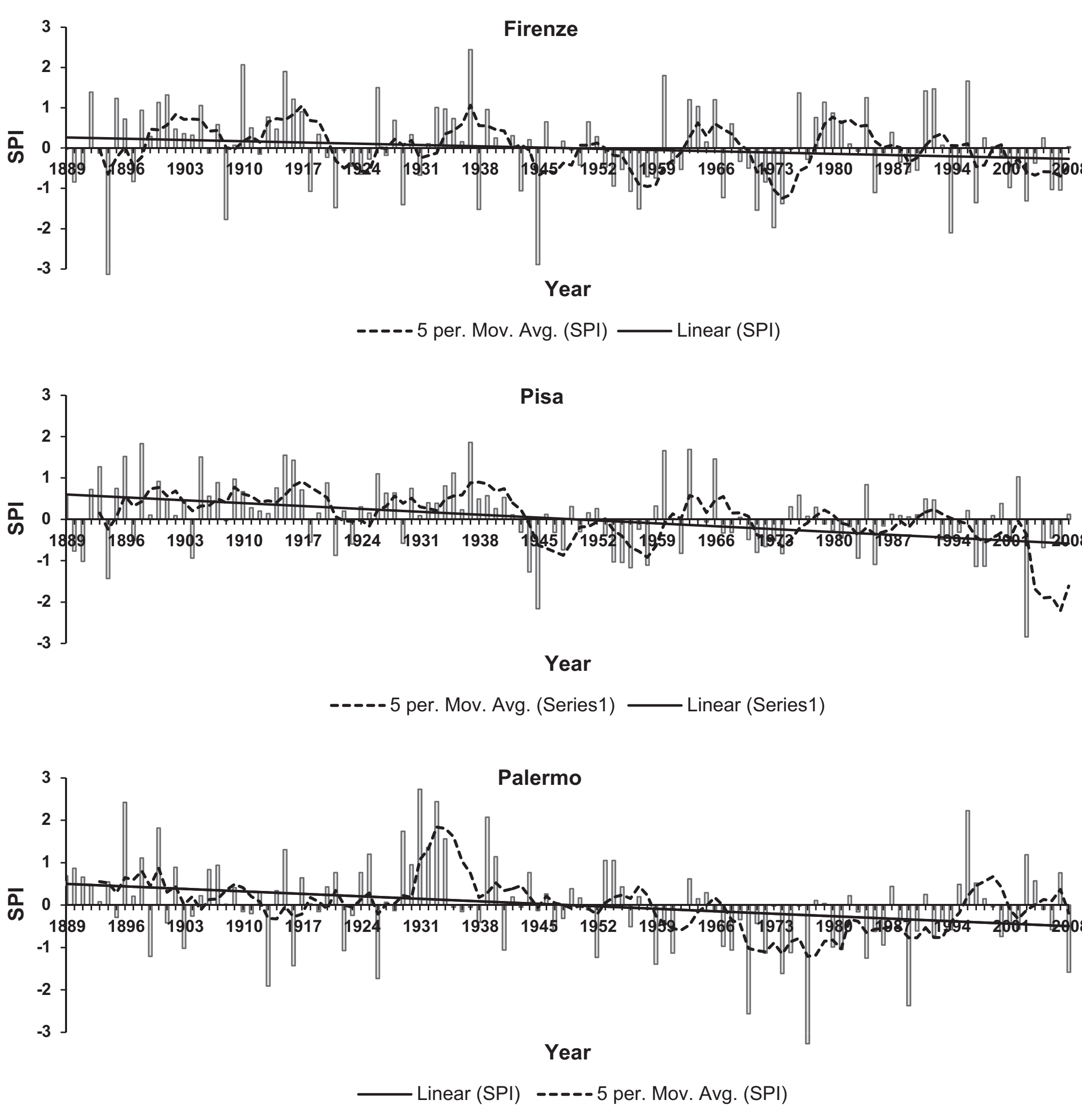

Fig. 4. Yearly Standardized Precipitation Index (SPI) values over the century at three locations of Italy.

Table 8
Years with different Standardized Precipitation Index (SPI) thresholds in two halves of the century.

Location/ Period	SPI < -1	SPI >1	SPI <0	SPI >0
Firenze				
1889–1948	8	11	23	36
1949–2008	12	10	36	24
t-test (*P*-level)	−0.98 (NS)	0.24 (NS)	−2.41 (0.01)	2.22 (0.01)
Pisa				
1889–1948	4	9	15	45
1949–2008	9	4	35	25
t-test (*P*-level)	−1.47 (0.07)	1.47 (0.07)	−3.90 (< 0.001)	3.90 (< 0.001)
Palermo				
1889–1948	7	12	23	37
1949–2008	13	4	37	21
t-test (*P*-level)	−1.47 (0.07)	2.17 (0.02)	−2.61 (0.001)	3.01 (0.001)

three locations. Moderate droughts (SPI < -1) showed significant ($P=0.07$) increase at Pisa and Palermo and non-significant increase at Firenze. The excess precipitation years (SPI >0), however, showed highly significant decrease at all the three locations. The years with SPI >1 too showed significant decline at Palermo ($P=0.02$) and Pisa ($P=0.07$).

4. Conclusions

To understand the climatic change with respect to changes in precipitation, a long time series daily precipitation data of 120 years at Firenze, Pisa and Palermo of Italy were analyzed over two time scales (averaging periods), *viz*., 10-year and half century (60-years). Within each time scale, not only annual precipitation but also seasonal and monthly precipitation patterns were studied. For identifying the precipitation changes in totality, multi-pronged approaches like (i) comparing the means over different time scales, (ii) working out long term trends, (iii) monitoring extreme precipitation events and (iv) use of climate indices were adopted.

The annual precipitation means at shorter time scale (decades) were found fluctuating in successive decades at all three locations. However, half century means of annual precipitation at Firenze, Pisa and Palermo, respectively showed significant reduction of 50, 148 and 84 mm in the 2nd half compared to its 1st half.

Seasonal precipitation pattern in two halves of the century showed no significant decline in the precipitation of any of the seasons across all three locations during the 2nd half compared to 1st half.

Monthly precipitation patterns in two halves of the century showed significant decline in the precipitation of three, five, and four months, respectively at Firenze, Pisa and Palermo in 2nd half of century compared to its 1st half.

Significant decline in the number of rainy days of all the four seasons of the year was noticed during the 2nd half compared to the 1st half of century at Pisa only. Highly significant decline in the annual rainy days was witnessed and rainy days per annum were less by 8 and 12 days at Firenze and Pisa, respectively in the 2nd half than in the 1st half.

Long-term (120 years) trend analysis of annual precipitation, rainy days and precipitation intensity revealed highly significant negative trend in rainy days at Firenze and Pisa and precipitation at Pisa and Palermo over the 20th century.

Analysis of changes in days with different threshold amounts of precipitation in later half of Century vis-à-vis the former half revealed an interesting phenomenon of highly significant increase in the events of low (< 1 mm) precipitation in the latter half of 20th century at all the three locations. Though increase in the extreme high precipitation events as a result of green house gas induced climatic change is a widely reported observation, increase in days with low precipitation (drizzle days) is a new finding in this study. Decline in rainy days with precipitation intensities of 5 to 15 mm (frequently occurring events) by 3 and 6 days per year at Pisa and Palermo in the latter half of the century is a matter of grave concern for this region that is likely to bear the brunt of abnormal warming (Vijaya Kumar et al., 2005).

The Standard Precipitation Index (SPI) of annual precipitation over the century depicted downward trend besides identifying dry years with higher intensity and longer duration in the later half than in the early half of the century at all three locations.

The long-term negative trend in rainy days and SPI besides increases in duration and intensities of droughts emphasizes the need for keeping closer watch on climate of central and southern Italy in view of their proximity to the desert area in the south and signs of desertification noticed in the Mediterranean region.

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