Dynamics of intense rainfalls in the southern half of European Russia for the period 1960-2015

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Abstract. Two time periods (1960-1986 and 1986-2015) were compared in terms of mean annual frequency and mean annual sum of warm season rainfalls to quantify general trends in the changing regime of heavy precipitation over the southern part of European Russia, which is the area of the most intensive agricultural activity. The identified trends were compared with the published assessment of the intensity trends of soil erosion processes. The prevalence of the increasing tendency in the frequency and amount of precipitation is demonstrated, which undergoes against a decrease in the rate of eroded sediment accumulation and against a decrease of linear growth rate of gullies. This result rather proves the crucial contribution of the snowmelt to the soil erosion over the studied area.

1. Introduction

The current century is characterized by global intensification and changes in the structure of the water cycle [1]. In accordance with the fifth assessment report of the Intergovernmental Panel on Climate Change [2], the coming decades are expected to have more intense rains. This theory is already being justified in regional studies in Europe and on the European territory of Russia in particular [3-7]. In general, the greater amount of precipitation leads to the greater soil erosion, which is one of the most important factors of arable land degradation.

This paper presents an analysis of trends in heavy precipitation of the warm season on the southern half of the East European Plain, which was chosen as the territory with the most intensive agricultural activity. The study is bounded to the period 1960-2015 to be comparable with evaluation of soil erosion rate trends based on the dating of sediments deposited in the bottoms of the first-order valleys using the bomb-derived and Chernobyl-derived ^{137}Cs. Such estimates for small catchments of steppe and forest-steppe zones can be found in [8, 9, 10].

2. Materials and methods

2.1. Site and meteorological data

The territory covered by the current study refers to the most cultivated land. This is the southern part of the forest zone, the forest-steppe and steppe zones (figure 1). Here the arable land accounts for 20-80% of the total area, and the role of soil surface runoff induced with rainfall is substantial.

The rainfall daily amount exceeding 10 mm threshold is conventionally indicated as potentially erosive [11], but, as reported by [12], the most destructive runoff power in soil losses is associated with extreme rainfalls featured by more than 40 mm of daily amount. Erosive potential of a rainfall is defined as the product of the kinetic energy and its maximum 30 minute intensity, and is shown to have correlation with daily amount of precipitation [13]. The latter fact makes it possible to use the frequency of erosion-hazardous precipitation, characterized by different daily quantities, as a surrogate to assess the possible trends of soil loss intensity caused by rainfall runoff.

The analysis is based on daily precipitation records freely provided by the Russian Institute of Hydrometeorological Information – World Data Centre (RIHMI-WDC; http://meteo.ru/english/climate/) [14, 15]. Each weather station falling into the study area was characterized by warm season (May-September) time series of frequency and amount of precipitation for six groups of daily sum of precipitation: >10 mm, 10-20 mm, 20-30 mm, 30-40 mm, 40-50 mm and >50 mm (twelve time series per weather station). Season (year) was excluded from the time series if more than 30% of daily data was absent. The stations selected for the analysis have no more than 20% of missing data in time series. 70 stations were chosen in total.

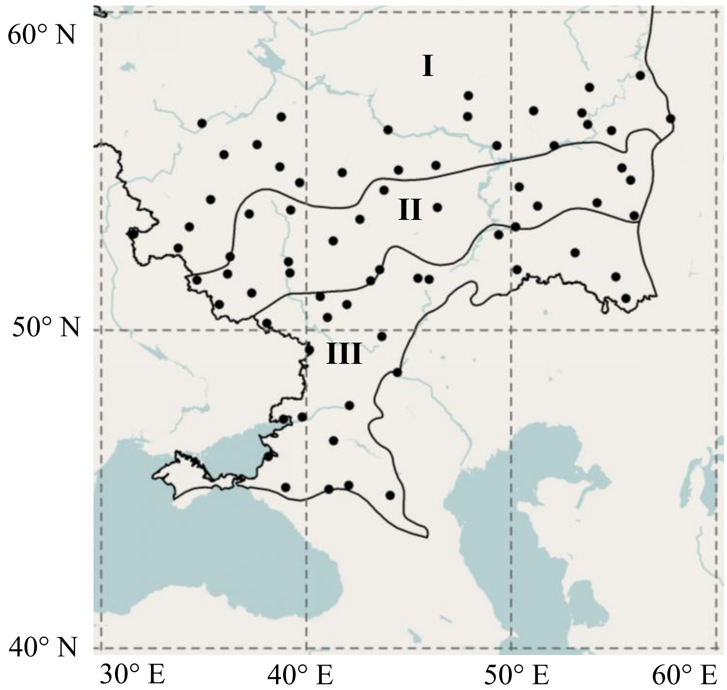

Figure 1. Scheme of landscape zones and weather stations. Zone numbering: (I) forest, (II) forest-steppe, (III) steppe zone. Forest zone is shown partly, because only its southern part is under study.

2.2. Statistical analysis

The aim of the study was to assess precipitation trends assuming its potential to change soil erosion rates and to compare observed rainfall trends (if any found) with available estimates of the trend of erosion processes on arable land in European Russia. Several published estimates of soil erosion rates used in this investigation are based on dating of soil deposition with use of ^{137}Cs which peak concentrations are due to testing of nuclear weapons in the atmosphere in 1954-1963 and the Chernobyl nuclear disaster in 1986 [8, 9, 10]. Because of this timing, all precipitation time series were divided into two time slices: from 1960 to 1986, and from 1986 (inclusive) to 2015. Depending on the changes of precipitation statistics between these two periods, two types of the precipitation dynamics can be articulated: (i) increasing and (ii) zero change or decreasing.

To quantify the change of warm season rainfall frequency the mean annual count of rainfalls during the warm season was calculated for each time period. The type of precipitation dynamics was inferred from the difference between mean annual counts: positive difference corresponds to increasing frequency, and negative difference corresponds to the decreasing rainfall frequency. The statistical significance of the ratio of mean annual counts was assessed using the Poisson test. It should be noted that this test assumes the count of rainfalls to be Poisson distributed, which might not be the case for

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very rare rains with high daily precipitation sums. So the estimates of statistical significance should be be taken only as additional illustrative evidence of substantial changes. Duration of time base for event count was adjusted at each weather station in accordance with recommendation of [7]: years with more than 30% of missing daily data were excluded from time series.

To quantify the change of amount of warm season precipitation, the difference in the medians of the annual sums of warm season rainfalls was calculated. The statistical significance of the difference was assessed using the Mann-Whitney test.

3. Results

At the beginning period under study (1960-1986), the forest, forest-steppe and steppe zones had similar features in terms of frequency and amount of precipitation, which is summarized in the table 1. On average, during a warm period, the meteorological stations have 3-9 rainfalls exceeding daily amount of 10 mm, which corresponds to 60-180 mm per season. The most erosive rainfall events with daily amount exceeding 40 mm per day of the warm season occur no more often than one event per 10 years.

Table 1. Precipitation characteristics of the warm season for the periods of time.

Daily amount of precipitation	Mean annual frequency of warm season rainfalls (minimum / median / maximum)		Mean summary precipitation of the warm season, mm (minimum / median / maximum)	
	1960-1986	1986-2015	1960-1986	1986-2015
>10 mm	3.4 / 6.7 / 9.4	2.7 / 7.3 / 9.9	61 / 126 / 181	47 / 140 / 226
10-20 mm	2.4 / 4.8 / 6.9	2.1 / 5.0 / 6.7	34 / 69 / 100	29 / 72 / 97
20-30 mm	0.6 / 1.2 / 2.2	0.4 / 1.5 / 2.3	15 / 30 / 55	11 / 36 / 56
30-40 mm	0.1 / 0.4 / 0.8	0.1 / 0.4 / 0.9	2 / 13 / 27	2 / 14 / 32
40-50 mm	0.0 / 0.1 / 0.3	0.0 / 0.2 / 0.6	0 / 5 / 15	0 / 8 / 28
>50 mm	0.0 / 0.1 / 0.4	0.0 / 0.1 / 0.4	0 / 5 / 31	0 / 6 / 29

Comparing the annual characteristics of the precipitation, a slight increase in the frequency and amount of warm season precipitation can be noted, irrespective of their daily amount (table 1). However, it should be emphasized, that the rate of change is tiny. The amplitude of changes is small, as well as counts of stations demonstrating statistically significant changes (tables 2, 3).

Table 2. Statistics of frequency shifts across the studied area. Shifts are computed as the difference between the mean annual warm season rainfall frequencies for the period of 1986-2015 and the 1960-1986.

Daily amount of precipitation	Minimum difference (decrease)	Median difference	Maximum difference (increase)	% of stations with increased frequency (& p-value < 0.05)	% of stations with zero changes or decreased frequency (& p-value < 0.05)
>10 mm	-1.3	0.4	2.7	79 (20)	21 (1)
10-20 mm	-1.0	0.1	1.6	60 (9)	40 (0)
20-30 mm	-0.6	0.2	0.9	70 (11)	30 (3)
30-40 mm	-0.3	0.1	0.5	60 (6)	40 (1)
40-50 mm	-0.3	0.1	0.4	73 (6)	27 (3)
>50 mm	-0.2	0.0	0.2	54 (1)	46 (4)

Analyzing the distribution of the frequency shifts (table 2) and the precipitation sum shifts (table 3), the prevalence of increasing tendencies over the downward ones is evident. The percent of station with upward changes is higher than for stations with zero or negative temporal changes, as well as 50% quantile (median) is above zero almost in all cases of daily amount of precipitation (tables 2, 3). This pattern is the most prominent for the broadest group of precipitation events with daily amount ">10 mm".

Table 3. Statistics of summary precipitation shifts across the studied area. Shifts are computed as the difference between the mean annual warm season rainfall sums for the periods of 1986-2015 and 1960-1986.

Daily amount of precipitation	Minimum difference (decrease)	Median difference	Maximum difference (increase)	% of stations with increased precipitation (& p-value < 0.05)	% of stations with zero changes or decreased precipitation (& p-value < 0.05)
>10 mm	-24	11	68	77 (17)	23 (1)
10-20 mm	-16	2	23	59 (9)	41 (0)
20-30 mm	-16	5	23	69 (15)	31 (3)
30-40 mm	-10	2	18	61 (7)	39 (1)
40-50 mm	-15	4	17	73 (13)	27 (3)
>50 mm	-21	1	15	53 (1)	47 (5)

The spatial patterns of frequency trends and the summary precipitation trends are similar. Despite diverse and heterogeneous pattern, when positive trends alternate with zero and negative ones, the positive trends for precipitation of daily amount >10 mm, 10-20 mm, 20-30 mm, 30-40 mm and 40-50 mm seem to dominate over the northern part of the territory under study (south border of the forest landscape zone) (figure 1a-b, figure 2a-b). The growth is either small or negative in south-eastern part of steppe zone and around Volga-Kama region. The group of rainfalls of daily amount of >50 mm exhibits a distinct increasing tendency around the Central Russian Upland (figure 2c-d).

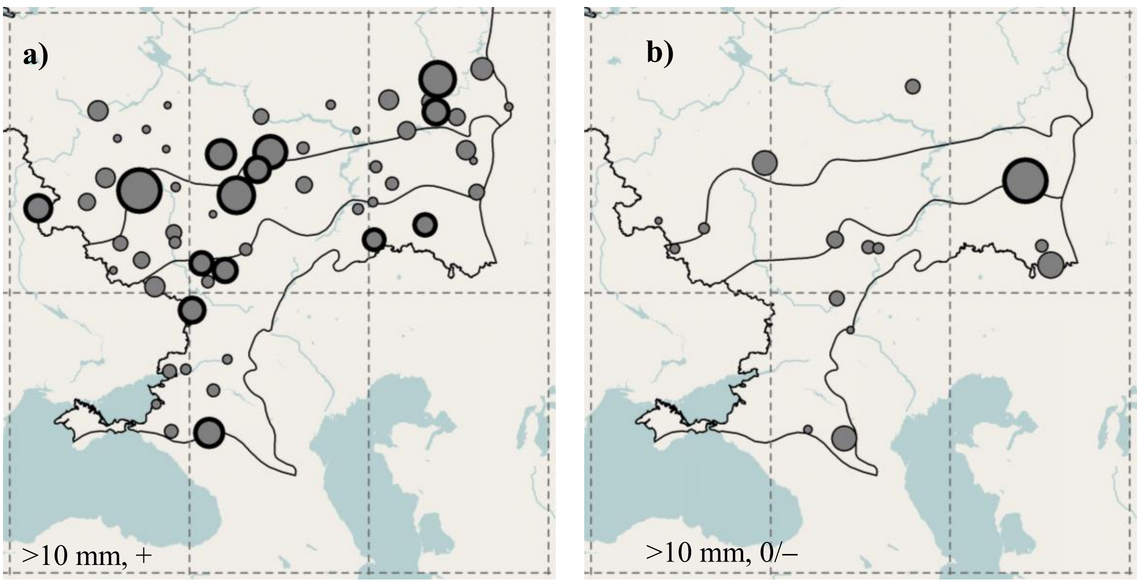

Figure 2. Precipitation frequency shifts between the periods of 1986-2015 and 1960-1986, general group of rainfall daily amount: >10 mm. Size of the points is proportional to the absolute difference of mean annual warm season rainfall frequencies (see statistics in table 2). A: Stations exhibiting increase of warm season rainfall frequency. B: Stations exhibiting zero changes or decrease of warm season rainfall frequency. Points with thicker outline denotes statistically significant rate of seasonal frequencies by 0.05 confidence level by the Poisson test of rates.

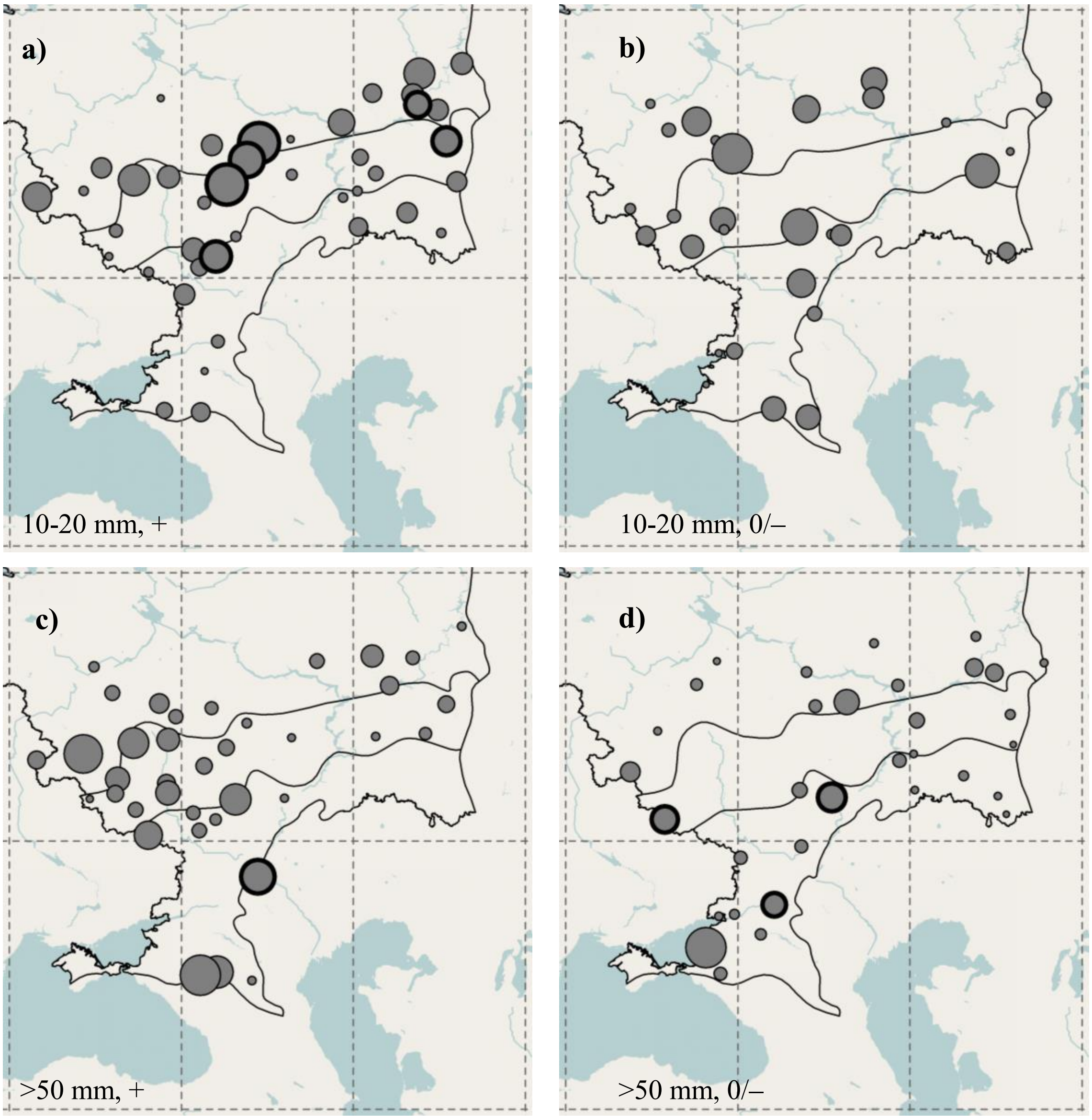

Figure 3. Precipitation seasonal summary precipitation shifts between the periods of 1986-2015 and 1960-1986. Size of the points is proportional to the absolute difference of the mean annual warm season rainfall sums (see statistics in table 3). A, B: Group of rainfall daily amount: 10-20 mm. C, D: Group of rainfall daily amount >50 mm. A, C: Stations exhibiting increase of warm season rainfall sum. B, D: Stations exhibiting zero changes or decrease of warm season rainfall sum. Points with thicker outline denote statistically significant difference of the medians by 0.05 confidence level by the Mann-Whitney test.

4. Discussion

According to the estimates of the volumes of accumulated eroded deposits in the catchments of the forest-steppe zone [8], during the period 1986-2015, the rate of erosion of soils from arable land decreased by half in comparison with the previous period of 1954-1986. The estimates gained in the research cited cover the Central Russian Upland, which meanwhile undergoes the increase of the precipitation of daily amount exceeding 50 mm (figure 3a).

The work of [16] uses the estimates of the linear growth of gullies to characterize the soil erosion rates in the south part of the forest landscape zones (Udmurt Republic). The rate of linear growth of gullies is decreasing [16], which contradicts to dynamics of potential erosive precipitation. The precipitation time series of weather stations around Udmurtia demonstrate upward trends.

This contradiction is evidence that slight changes of the precipitation regime in forest, forest-steppe and steppe zones did not change the general tendency of erosion processes. This outcome argues into the key role of the surface runoff from the slopes during the snowmelt for erosion processes. According to the [17-19], the intensity of surface runoff during snow melting is decreasing because of reduction of frozen soil depth during the winter. If the tendency to an increase in erosion-hazardous precipitation persists as well as the decrease of the intensity of surface runoff during the spring snow melt, an increase in the contribution of showers to soil erosion can be expected.

5. Conclusion

Precipitation regime of the warm season shows upward trends of frequency and total sum at the southern boundary of the forest landscape zone, in forest-steppe and steppe zones. The rate of this increase is moderate or rather small and did not affect the directionality of the erosive processes towards decline.

Acknowledgments
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