RESEARCH PAPER

TRENDS IN EXTREME WEATHER EVENTS WITH SOCIO-ECONOMIC DAMAGE OVER THE PERIOD 1991-2019 IN RUSSIA AND ITS REGIONS

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ABSTRACT. Increased number of extreme weather events is one of the most serious hazards of climate change over the territory of Russia. However, there is a lack of comprehensive analysis of the number of extreme weather events that caused social and economic damage in the country and its regions. This paper analyzes changes in the total number of events with damage (meteorological for the period 1991-2019 and agrometeorological – for 2004-2019), disaggregated by their types and by regions. The Mann-Kendall test is applied to detect statistical significance (0.05 level of significance, normal distribution). The results show an increase in the number of meteorological extreme events with damage for 1990-2019 in Russia from 130 to 257 events per year on average for the 1990s and 2010s, respectively, while the proportion of events with damage in relation to the total number of extreme events decreased over this period. We found statistically significant trends only for a few types of extreme events: hot and cold temperature, strong wind, heavy rain and droughts (increase by 0.9, 9.4, 11.4, 25.9 and 13.3 events/10 years, respectively). Number of heavy rain precipitation events is the only unidirectional stable growth trend. Unusual increasing trend in cold extreme events with damage in Russia can be attributed to the greater damage to the economy and population from cold extremes than hot ones. The regional distribution of trends across the territory of the Russian Federation is heterogeneous. However, significant changes in the number of extreme events of strong winds, heavy rains and soil drought by regions are statistically positive and observed mostly in some southern and central regions of European part and the Western Siberia. The development of adaptation plans to the negative effects of climate change is a first priority for these regions. A system for monitoring economic and non-economic damage from extreme events must be developed in Russia.

KEYWORDS: extreme weather events, socio-economic damage, trends, regional distribution, climate change

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INTRODUCTION

Global climate change has increased the number and intensity of extreme weather events around the world. Continued warming will cause statistically significant changes in extreme events globally and for large regions (e.g., Masson-Delmotte et al. 2021). Many studies report observed and future increases in temperature extremes, heavy precipitation, and drought extremes and its regional distribution around the world (Spinoni et al. 2014; Donat et al. 2016; Knutson and Zeng, 2018; Sun et al. 2020; Dunn et al. 2020; Wu et al. 2021; Seneviratne et al. 2021; Rabiei et al. 2022). According to the World Meteorological Organization's report (WMO, 2021), the number of disasters increased fivefold in the 50-year period from 1970 to 2019, because of climate change, more extreme weather and improved reporting. During this period, there were more than 11,000 disasters associated with these hazards worldwide, resulting in just over 2 million deaths and $3.64 trillion in damages (WMO, 2021).

As for the Russian Federation, there is no reliable data yet on the total (economic and non-economic) damage caused by changes in climate parameters and an increase in the number of extreme events. There are sporadic reports of major disasters in Russia, such as the 2019 Irkutsk flood causing a direct economic damage of $460 million[1]. The extreme downpours in the south of the European part in the Krasnodar Territory in the summer of 2012 resulted in 177

[1]https://www.vedomosti.ru/politics/news/2019/07/06/805984-zatrati

deaths and direct losses of $250 thousand[2]. The economic damage from wildfires in 2021 estimated as high as $140 million[3]. The year 2021 was a record-breaking year for the area affected by fire. Nearly 15 thousand wildfires occurred on an area of more than 10 million hectares. Moreover, the direct potential damage from permafrost thaw in Russia may reach up to US$ 132 billion (total) and ~ US$ 15 billion for residential infrastructure alone (Melnikov et al. 2022).

The available Russian scientific literature provides analyses of changes in climatic parameters and extreme events in the country. Increased duration and intensity of heat waves and droughts are reported for central and southern European part of Russia (Bardin and Platova, 2019; Pavlova et al. 2020; Cherenkova and Semenov, 2021). Annual reports of the Federal Service for Hydrometeorology and Environmental Monitoring of the Russian Federation (Roshydromet) indicate that the changes in the precipitation regime in Russia are dominated by an increase in their annual amounts: the trend is 2.2% of the average /10 years, but the distribution is highly uneven (Report of peculiarities of climate…, 2022). Some extreme values of precipitation are observed in spring in Western Siberia (Third assessment report…, 2022; Zolina and Buligina, 2016; Khlebnikova et al. 2019); those are often followed by large flooding events. The frequency of strong winds, heavy precipitation and frost has been the highest in recent years among all weather extremes, accounting for 77% of all meteorological extreme events (Report of peculiarities of climate…, 2022). However, there is a lack of comprehensive regional analysis of the statistics on extreme events annually collected by Roshydromet that caused social[4] and economic[5] damage.

As part of the commitment to develop regional adaptation plans in 2022 (National action plan…, 2019), it is particularly relevant to assess regional trends in extreme weather events that have caused social and economic damage as well as to rank regions according to the priority of adaptation measures. Adaptation should include measures aimed at reducing damage from hazards expected in the coming decades (preventive adaptation) as well as measures responding to already observed changes in the number and intensity of extreme weather events and climatic parameters.

The purpose of this paper is a comprehensive analysis of the dynamics of extreme events causing social and material damage in the aggregate, separately by their types and by regions in Russia over the period from 1991 to 2019. Statistical significance of trends is assessed. The objectives of the study include:
- analyze trends in the total number of extreme weather events with and without socio-economic damage in 1991 - 2019 in Russia and by regions, identifying statistically significant changes;
- statistical analysis of trends in the number of extreme events with damage by its types in the country;
- statistical analysis of regional trends in the number of extreme events with damage by its types;
- identify the regions most affected by extreme events associated with socio-economic damage with the primary task of developing and implementing adaptation plans to the negative effects of climate change.

METHODS

Data sources. The data available in Roshydromet on extreme meteorological events with social and economic damage are reviewed: very strong wind; hurricane wind (hurricane); squall; tornado; heavy downpour; very heavy rain (very heavy rain with snow, very heavy wet snow, very heavy snow with rain); very heavy snow; continuous heavy rain; large hail; severe snowstorm; severe dust (sand) storm; severe fog (thick fog); severe ice and frost; severe frost; abnormally cold weather; severe heat; abnormally hot weather; extreme fire danger; avalanches. The database of the All-Russian Research Institute of Hydrometeorological Information - World Data Center of the Federal Service for Hydrometeorology and Environmental Monitoring is used (Shamin et al. 2021). Abrupt change in weather and complex adverse events are considered in our analyses as separate events.

Considering that agriculture, especially crop production, is one of the most vulnerable sectors of the economy to climate change (Third assessment report…, 2022), some agrometeorological extreme events are also included in the analysis. The corresponding data of Roshydromet on agrometeorological extreme events (including the dataset (Zhemchugova, 2016)) are obtained for the period from 2004 to 2019. Only "soil drought" event data are used in the analysis. Soil drought is defined as an event during the vegetation period of crops for a period of at least three consecutive ten-day periods with reserves of productive moisture in the soil layer 0-20 cm are not more than 10 mm or for a period of at least 20 days, if at the beginning of the drought period the reserves of productive moisture in the layer 0-100 cm were less than 50 mm. Prolonged drought (more than 1 month) is considered as a separate event in the analysis.

Hydrological extreme events are classified as secondary correlated hazards resulting from meteorological events and are excluded from the analysis. This approach also made it possible to exclude such secondary correlated consequences of climate change as an increase in the depth of seasonal thawing of permafrost soils, which is more logical to investigate separately (Edel'geriev and Romanovskaya, 2020).

Taking into account that one of the sources of this dataset is the meteorological network of Roshydromet, it should be considered that the homogeneity of the data series can be somewhat disturbed by the decrease in the number of stations in the 1990s and their growth in the beginning of the 21st century.

Heterogeneity of the data can also be determined by subjectivity in the interpretation of the single event if several threshold criteria are met (e.g., "very heavy rain" and "heavy downpour") (Chernokulsky et al. 2022). The heterogeneity of the data series used can also be determined by the fact of fixation or not of social and/or economic damage. We tried to minimize the effect of such heterogeneity of series by aggregation of data on certain types of extreme events into one indicator (e.g. sum of events with heavy downpour, very heavy rain (very heavy rain with snow, very heavy wet snow, very heavy snow with rain) and continuous heavy rain).

Period considered. The period from 1991 to 2019 is analyzed (only soil drought events from 2004 to 2019). Data for 2020 are not taken into account because of the high temperature anomaly in Russia in that year, which requires separate investigation and analysis of seasonal extreme events. Merely including 2020 could have a distorting effect on the overall trend analyses presented in this paper.

Although the considered trends of different extreme events have various durations (1991-2019; 2004-2019) this should not introduce strong distortions in our results, as our

[2]https://www.vedomosti.ru/finance/articles/2012/08/06/strahovoj_milliard
[3]https://tass.ru/ekonomika/13265341
[4]Losses associated with the life, health and spiritual values of an individual, social groups and society, associated with an increase in mortality, morbidity, disability, and a decrease in the level of life support; is defined as irretrievable and sanitary losses of people, material losses of personal property, costs for the treatment of victims and for the restoration of working capacity, moral and psychological costs and a decrease in the quality of life.
[5]Economic damage associated with material losses and damage or destruction of objects of the economy, its infrastructure and violations of production and cooperation relations.

work did not aim to aggregate all the considered trends into any single indicator.

At the same time, there is an understanding that the study period influences trend detection, i.e., climate data records may contain large-scale periodic behavior. It is especially important when analyzing data series for very large areas, when several large-scale atmospheric circulation models have the main influence on periodicity of time series. Therefore, we carry out the analysis regionally across the country and present the area of the studied regions (see Supplemental material, Table 1).

Regional analysis. Statistical processing of primary data on extreme events causing economic and social damage included summarizing the number of events by their type in each region of the Russian Federation per year. In order to avoid the possible distorting effects of incomparable regional areas we determined the specific number of events in each region per 100,000 km^2 socio-economically developed area and estimated the average 10-year change in the number of cases over the entire time series by each region. Developing an approach used in (Baburin and Badina, 2015) socio-economically developed area in our research is defined as a sum of settlements area, industrial land, agricultural land, forest land and protected areas[6] in each subject of Russia. We used that number in calculations if the sum of chosen categories of lands differed from the total area of the subject by more than 10%, in other cases the total area of the subject is used.

A total of 85 regions of the country are considered. Large events observed in several regions are considered as a separate event in each region. However, for the national total such events are counted as one.

Statistical analysis. The Mann-Kendall test is used to determine the level of significance (Gilbert 1987). Mann-Kendall is one of non-parametric tests commonly used for trend analysis of meteorological and climate data sets. Compared to parametric tests (e.g., regression coefficient test) this test requires no prior assumptions on the type of probability distribution of the data deviation from the long-term trend and is less sensitive to outliers (Wang et al. 2020). The software MAKESENS (Salmi et al. 2002) is applied for our analysis. The 0.05 significance level and normal distribution is used.

Yue et al. (2002) raises concerns about a series of hydrological events with less than 40 values for application of the Mann-Kendall test. However, according to (Salmi et al. 2002) MAKESENS software can be used for data series of 10 or more values that are normally distributed and not directly correlated with each other (Helsel and Hirsch 1992), which is valid in our case.

The results obtained are presented below in the following order from the aggregate analysis for the country as a whole to trends in single types of extreme events and their distribution across Russian regions.

RESULTS

Trends in the total number of extreme weather events associated with socio-economic damage in 1991 – 2019 in Russia and its regional distribution.

The overall dynamics of the number of extreme weather events that caused economic and social damage in Russia for the period from 1991 to 2019 indicate a sharp increase in the number of such events in the country between the 1990s and 2000s years (fig 1) from 130 to 237 events per year in average (1.8 times) with 0.001 level of significance, while for the beginning of the 21st century the trend in the number of events with social and economic damage increased to an average of 257 events and showed only 0.05 level of significance by Mann-Kendall test. A similar upward trend is obtained in (Korshunov et al. 2019) for the total number of extreme damage events, including all types of meteorological and hydrological events, in Russia in 2008-2017 compared to 1997-2008.

When comparing the data on total number of extreme weather events, including those which were not accompanied by economic damage (Panfutova, 2008; Report on the peculiarities of climate…, 2022), it can be seen that the same constant level of significance is observed for the growth between both decades: from the 1990s to the 2000s and from the 2000s to the 2010s (fig 1). The steady upward trend is consistent with climate monitoring data in Russia and the globe as a whole, where there has been a steady increase in average annual surface temperature and changes in other climatic parameters (Report of peculiarities of climate…, 2022; Masson-Delmotte et al. 2021).

The number of extreme events which are not accompanied by damage to the economy and population is gradually increasing from 1991 to 2019: in the 1990s the average share of events without associated damage was about 37% of total, and in 2010s – about 53% of the total on average over 10 years. Apparently, this can be explained either by the growth of low-intensity extreme events, the level of which reaches the criteria of extreme events, but does not cause material damage, or by methodological heterogeneity of data series: improvement in the accounting of dangerous phenomena without damage and/or imperfect determination of damage from some

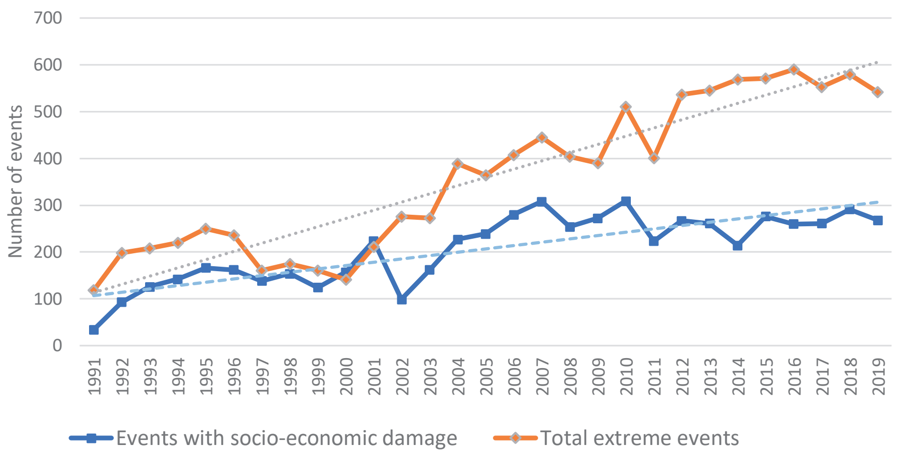

Fig. 1. Comparison of trends in the total number of extreme weather events and extreme weather events that caused economic and social damage in Russia for 1991-2019 (according to Roshydromet data)

[6]Economic damage to forests and protected areas is reflected in annual and periodic materials of the State forest registry and in reporting data on the use, protection, defense and reproduction of forests.

types of extreme events in Russia. The latter issue is discussed, for instance, by (Panfutova 2008; Chernokulsky et al. 2022).

A further possibility to explain the reasons for the observed separation of the two trends could be e.g. the improvement of early warning systems and monitoring technologies or the implementation of proactive measures to adapt the economy and population to extreme events. However, given that in Russia during the period under study we have no evidence of either, these explanations remain only at the hypothetical level.

The methodological homogeneity of data series on meteorological events with and without damage needs to be further investigated, given that the annual climate damage value is the primary justification for financing additional mitigation and adaptation measures in the country.

The total number of meteorological extreme events associated with damage has multidirectional trends across Russian regions (fig 2). The table 1 in the supplementary material presents regional data, accompanied by statistical analysis. There are regions in the country where the number of meteorological hazards is decreasing: Pskov region shows the greatest tendency to decrease by 1.8 events per 100 th. km^2 over 1991-2019 at a significance level of 0.01. There are regions where the number of hazards statistically increases at a significance level of 0.001 (see table 1 in the supplementary material). The highest growth trends are observed in 5 regions in the south of European Russia; those are marked in red in Figure 2. However, they are not always statistically significant: the trends for the Republic of North Ossetia-Alania, the Krasnodar Territory and the Republic of Crimea are significant at the 0.001 level, while the trend for the Kabardino-Balkar Republic is significant at the 0.05 level, and the trend for the Republic of Adygea is unsignificant.

Similar results were obtained in (Shamin and Sanina 2019), where a regional analysis of the same Roshydromet data for 2009-2018 demonstrates the absence of significant trends in the number of extreme events with damage for the majority of the selected 19 regions of the Russian Federation.

Trends in extreme weather events associated with socio-economic damage by type.

Applying the Mann-Kendall test, we found statistical trends in the number of events for only a few types of extreme events: hot temperature extremes, cold temperature extremes, strong wind events, heavy rain events and extreme events of droughts. No statistically significant results were found for a series of other types of extreme events. In the following, we consider only those types of events characterized by static results (Fig 3).

For **hot temperature extreme** events (which is the total of severe heat events and abnormally hot weather events) there has been a slightly increasing trend in Russia since 1991 with statistical significance (fig 3a). This trend is heavily influenced by two outliers in 1998 and 2010, and the decadal average for 2001-2010 is higher than the next decade of the 21st century.

Our results are in good agreement with the general trend of extreme hot events: many studies have shown that the number and intensity of extreme hot temperature events are significantly increasing both globally and within the territory of Russia (Donat et al. 2016; Bardin and Platova 2019; Dunn et al. 2020; Wu et al. 2021; Seneviratne et al. 2021; Report of peculiarities of climate…, 2022; Nita et al. 2022).

Cold temperature extremes on figure 3b are the totals of annual severe frost events and abnormally cold weather events. The growing number of such events in Russia is statistically significant. However, there is a high interannual variance compared with the trend of hot extremes in fig 3a in the number of cold extreme events caused damage.

The increasing trend in cold temperature extremes associated with damage found in our study is somewhat contrary to the literature: a significant decrease in the intensity and frequency of extreme cold events has been reported (Donat et al. 2016; Masson-Delmotte et al. 2021). A possible explanation for these discrepancies between our results and those in the literature is that we do not analyze all extreme temperature events, but only the part of them that caused social and economic damage (fig 1). As discussed above, there may have been an increase in the number of relatively mild extreme events with no

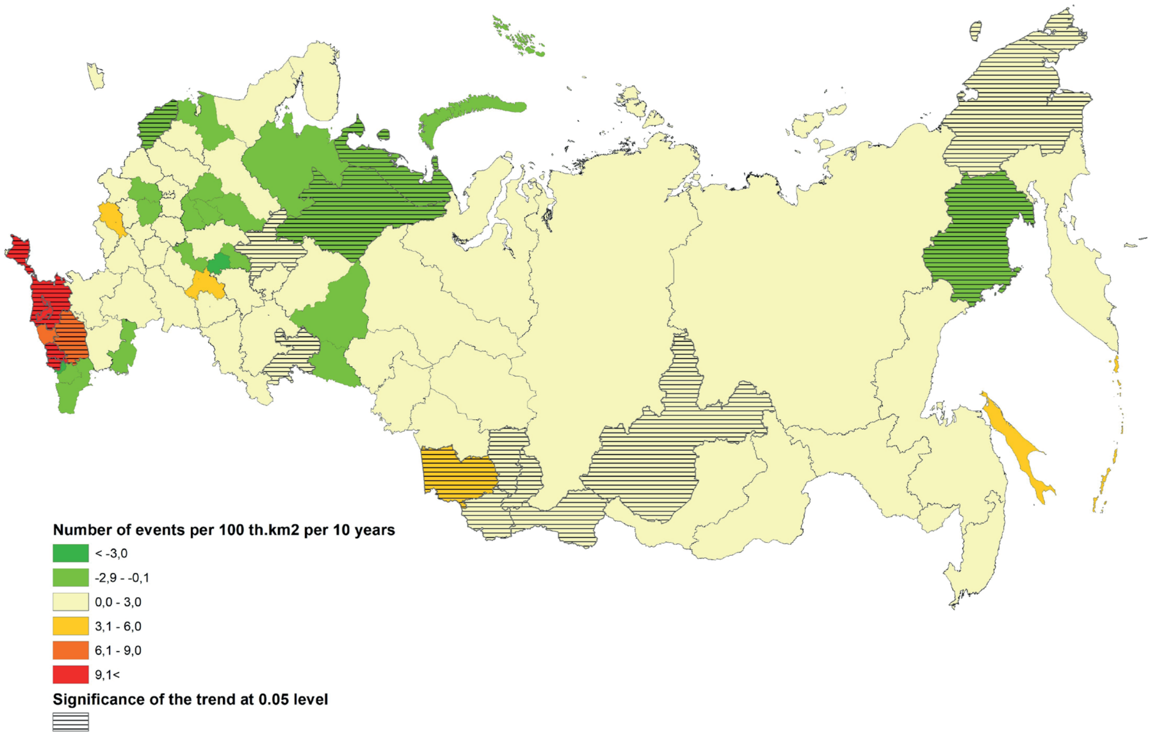

Fig. 2. Trends in the number of extreme weather events associated with socio-economic damage by regions of Russia, change in the number of events per 100 th. km^2 per 10 years during 1991-2019 period

subsequent physical loss or damage in the 21st century. Furthermore, it is logical to assume that extreme cold temperature events result in more significant damage to the economy and population than hot ones.

The clear significant trends are observed for **strong wind events** (fig 3c) and **heavy rain precipitation extreme events** with damage (fig 3d). The dynamic of heavy precipitation extremes is the only unidirectional steady growth trend.

An increase in the frequency of heavy precipitation has been observed worldwide, as well in Russia (Zolina and Buligina, 2016; Knutson and Zeng, 2018; Sun et al. 2020; Dunn et al. 2020; Seneviratne et al. 2021; Chernokulsky et al. 2022). Our results are in good agreement with this observation. The increase of heavy precipitation is obtained for the territory of the neighboring countries (e.g., Sumak and Semenova 2019).

The overall dynamics of the number of soil drought events with material damage indicates an unsignificant variations in the annual number of drought events in the Russian Federation since 2004 while atmospheric drought events as well as totals for droughts show significant increase (fig 3e). More than 90% of the recorded soil drought events in Russia were accompanied by socio-economic damage to crops and populations. Moreover, in recent years: 2012, 2013, 2015, 2017 and 2019, absolutely all registered extreme events on drought caused socio-economic damage. Thus, there is no problem separating total extreme events from events with damage in the case of a drought.

Regional trends in extreme weather events associated with socio-economic damage by types.

Analysis of the regional distribution shows that the largest changes in the number of extreme events are characteristic of the central and southern regions of the European part of Russia, as well as few regions in the central and southern parts of Western Siberia (see Figure 4 and the Table 1 in supplementary material).

Hot temperatures extremes. The regions with positive change in the numbers of hot temperature events are belong to extreme continental climate in the south of Ural and Siberia as well as central regions in European part of Russia (e.g. in Belgorod Region and Buryatia Republic increase in the number

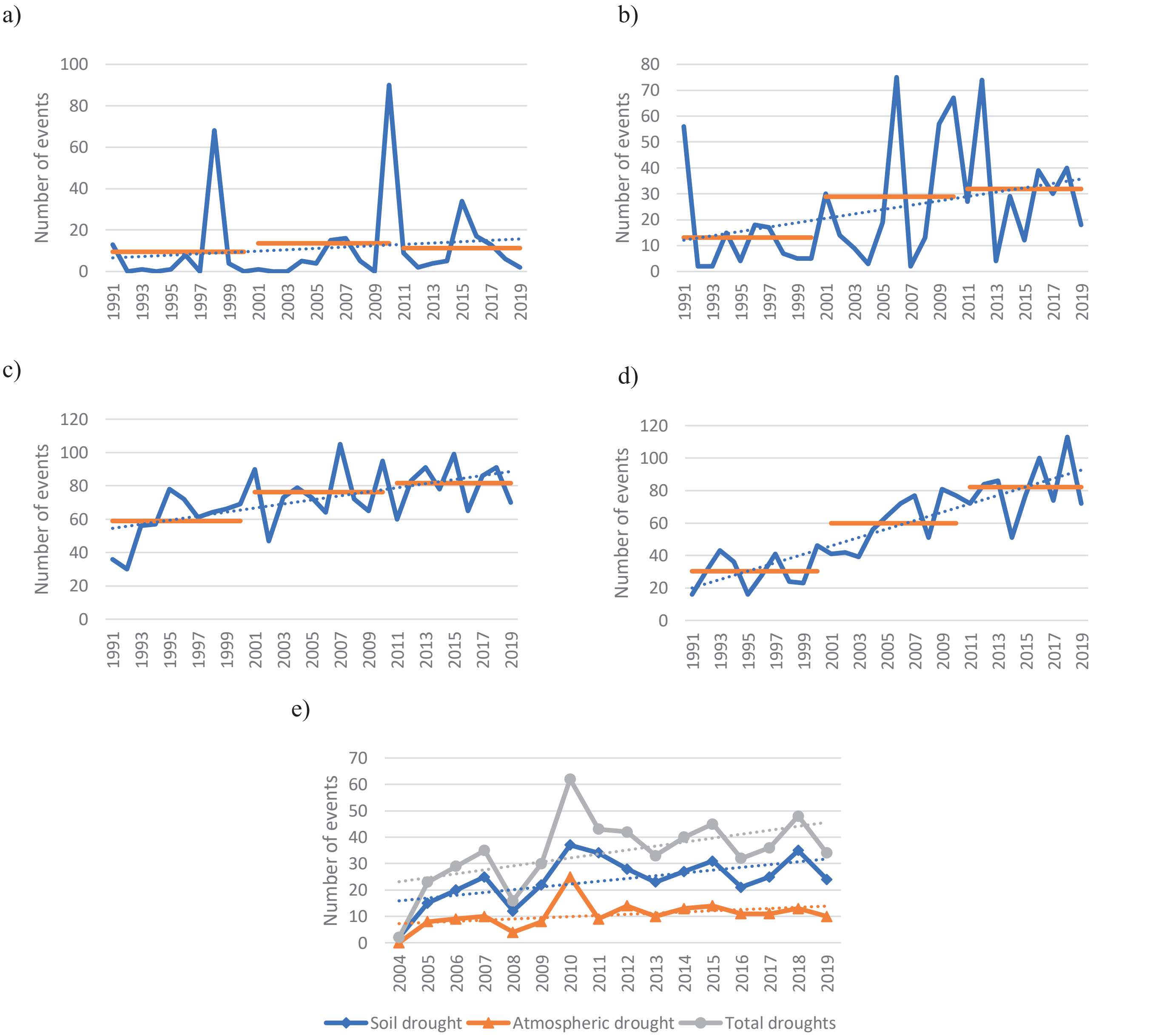

Fig. 3. Dynamic of the number of extreme events associated with social and economic damage in Russia for 1991-2019 and its decade's averages: a) the totals of severe heat events and abnormally hot weather; b) the totals of severe frost and abnormally cold weather events; c) very strong wind events; d) the totals of heavy downpour events, very heavy rain and continuous heavy rain events; e) events of soil drought, atmospheric drought and total number of drought events for 2004-2019. The dotted lines are the corresponding linear trends.

of events by 0,4 per per 100 th. km²/10 years). Negative trends observed in the Caucasus region (e.g. in the Kabardino-Balkar Republic decreased by -0,8 in numbers of events per per 100 th. km²/10 years) and few regions in the central part of Volga Federal District (e.g. in the Republic of Mary El change is -0,4 in numbers of events per per 100 th. km²/10 years) (fig 4a).

Cold temperature extremes. Positive trends in cold extremes are found in few central regions in the European part of Russia, such as Bryansk (by 0,8 numbers of events per per 100 th. km²/10 years), Lipetsk (by 0,9), Vladimir (by 0,6), Ivanovo (by 0,6), Kaluga (by 0,8), Moscow (by 0,3) regions, and south-east regions of Western Siberia: Altai Territory (by 0,3), Altai Republic (by 0,5), Novosibirsk (by 0,3), Kemerovo (by 0,6) Regions (fig 4b, Table 1 in supplementary material). The latter is in a good agreement with general dependencies in observed climate change within the territory of the Russian Federation (Report on the peculiarities of climate…, 2022). However, the Mann-Kendall test applied shows that these regional trends are not statistically significant.

The regional distribution of extreme cold temperature events (fig 4b) is well explained by the general regional time series of spatially averaged temperature anomalies for the period of 1976-2021 for all regions of country as represented in the regular Report on the peculiarities of climate on the territory of the Russian Federation of Roshydromet. The Siberian winter cooling zone in southern Western Siberia is reported here. This cooling was first detected for the period 1976-2010 and reached its maximum for the period 1976-2014 (the trend value in the center reached -0.54°C/10 years). Currently, the cooling is much less pronounced (-0.1°C/10 years in the south of Western Siberia) (Report on the peculiarities of climate…, 2022). As our study showed, the number of extreme cold temperature events that caused socio-economic damage increased in the same area.

Strong wind extremes. The largest negative significant wind trend is observed in the Karachaevo-Circassian Republic (by -2,6 numbers of events per per 100 th. km²/10 years) and positive trends are observed in the Republic of North Ossetia-Alania (by 12,2) and the Republic of Crimea (by 3,8) (fig 4c, Table 1 in supplementary material). The high value for the Kabardino-Balkarian Republic (by 3,4), marked in dark green in Figure 4c as well, is not statistically significant. The lack of literature data on trends in extreme winds is discussed in the most recent IPCC assessment report (Masson-Delmotte et al. 2021). It is concluded that the observed intensity of extreme winds is becoming less

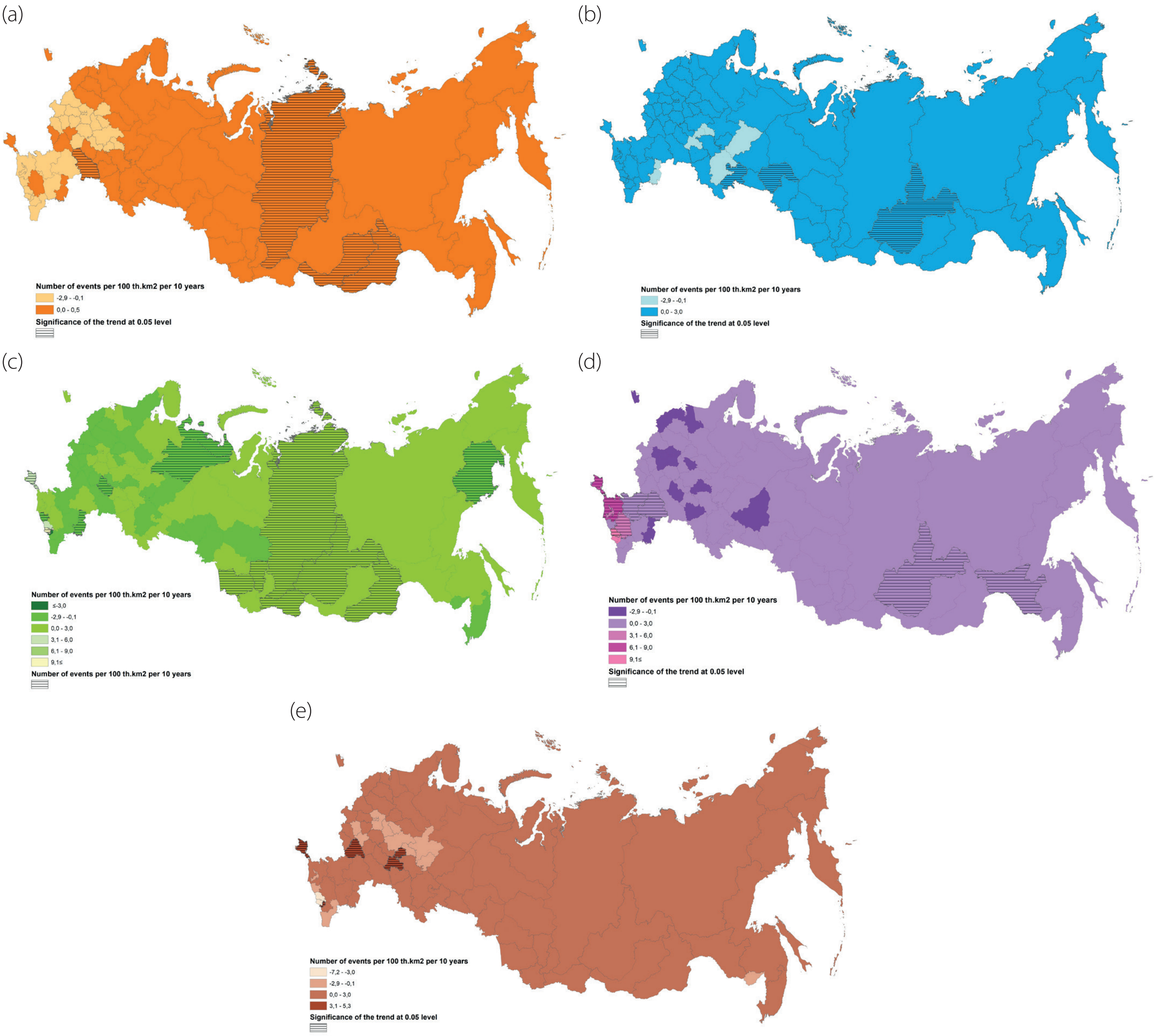

Fig. 4. Regional changes in the number of extreme events that caused economic and social damage, number of events per per 100 th. km²/10 years: a) hot temperature extremes from 1991 to 2019; b) cold temperature extremes from 1991 to 2019; c) strong wind events from 1991 to 2019; d) heavy rains from 1991 to 2019; e) soil drought from 2004 to 2019.

severe in the lower to mid-latitudes, while becoming more severe in higher latitudes poleward of 60 degrees (low confidence). Our results show that, in general, there are no significant trends in strong winds events on the territory of the Russian Federation regardless of latitude. The only statistically significant changes are noted for several southern regions of the European part of Russia. All of them are located below 48°N.

Heavy rain extremes. In terms of heavy precipitation, the change in the extreme events is distributed unevenly across the country, with both areas with a decrease in the number of downpours that caused economic damage and with an increase (fig 4d). The Mann-Kendall test showed that statistically significant positive trends in heavy precipitation are observed for the southern regions of the European part of Russia and Caucasus region: the Kabardino-Balkar Republic (by 12,7 numbers of events per per 100 th. km^2/10 years), the Krasnodar Territory (by 7,4), Stavropol Territory (by 4,0) and the maximum for the Republic of North Ossetia-Alania[7] (by 31,7).

Significant trends in the increase of heavy rain events detected in our research in the south of Siberia and Far East are consistent with results of investigation of atmospheric severe convective events in Russia (Chernokulsky et al. 2022). At the same time, the analysis of Chernokulsky et al. for the warm period of the year found no significant increase in the number of heavy rains in the south of the European part of our country, which was found in our work. Apparently, this could be explained both by consideration of the full calendar year in our study, and by high population density and infrastructure in these regions, leading to increased frequency of fixation of socio-economic damage. However, statistically significant trends are not observed in all regions of Russia (fig 4d). The lack of significant trends in heavy rains over large areas has also been noted by other authors (Mass et al. 2011; Sun et al. 2020).

Soil drought extremes. The number of soil drought events in most of the country is unchanged or slightly decreasing (fig 4e), which, in turn, may be associated with an increase in the average annual precipitation in most regions of the Russian Federation in recent years (Report on the peculiarities of climate…, 2022). At the same time, the central and southern regions of the European part of Russia (excluding the North Caucasus republics) are particularly exposed to the increase in the number of drought events: the largest trends are observed (in descending order) in the Republics of Crimea (by 5,3 numbers of events per per 100 th. km^2/10 years), Chuvashia (by 5,3), Ingushetia (by 3,4), Ulyanovsk (by 3,4) and Voronezh (by 3,2) regions.

The largest growing trends in the frequency of soil drought extreme events is observed for central and some southern regions of the European part of Russia. The same results are reported in many studies (Pavlova et al. 2020; Bardin and Platova, 2019; Cherenkova et al. 2020; Dunn et al. 2020; Cherenkova and Semenov, 2021). The trends in frequency of soil drought extreme events in the Asian part of Russia are on average an order of magnitude lower compared to the European part. There the largest positive trend is characteristic of the Tyumen region (south of the Western Siberia), but still statistically insignificant. Most other regions in the Asian part show inconsistent, mostly decreasing trends in the number of soil drought extreme events (fig 4e). Similar results obtained for observed and projected climate regimes in Russia in other studies (Spinoni et al. 2014; Khlebnikova et al. 2019; Report on the peculiarities of climate…, 2022; Seneviratne et al. 2021).

CONCLUSION

Our results confirm global trends in the increase of extreme weather events, both with and without socio-economic damage, over the past 30 years on the territory of the Russian Federation. While the overall growth trend in the number of extreme events with damage was similar to the growth trend in the total number of extreme events (with and without damage) during the 1990s-2000s, it lags significantly behind the growth rate of the total number of extreme weather events in the country during the two decades of the 21st century. The proportion of events with damage in relation to the total number of extreme events decreased over this period. This can be explained either by the growth of low-intensity extreme events, the level of which reaches the criteria of extreme events, but does not cause material damage, or by methodological heterogeneity of data series. In any case the divergence in trends requires further methodological investigation.

Statistically significant trends in the number of events found only for a few types of extreme events: hot temperature extremes, cold temperature extremes, strong wind events, heavy rain events and extreme events of droughts. Number of heavy rain precipitation events is the only unidirectional stable growth trend. Unusual growing trend in cold extreme events with damage in Russia may be explained by more significant damage to the economy and population from cold extremes than hot ones.

The distribution of trends in changes in different types of extreme events with damage is heterogeneous over the territory of the Russian Federation: there are regions with both negative and positive trends. Statistically significant changes in the number of extreme events with strong winds, heavy rains, soil drought and total meteorological extreme events are generally positive and are observed in some southern and central regions of the European part and few regions in the Western Siberia of Russia: the Kabardino-Balkar, Crimea, Adygea, Ingushetia, Tatarstan, Khakassia and Chuvashia Republics, Altai and Krasnodar Territories, Belgorod, Bryansk, Kursk, Samara, Smolensk and Ulyanovsk regions. The development and fast implementation of regional adaptation plans is a first priority for these regions considering the density of population in these areas as well as agriculture production as a main economic activity.

Further research is needed to examine the intensity of individual extreme events and the economic and non-economic damage they cause. The latter includes losses of ecosystem services, damage to public health, forced migration, etc. The dynamics of this parameter shows the need for additional mitigation and adaptation measures, and is also an indicator of the success (effectiveness) of these measures. It would be advisable to develop methodological research in the field of climate change damage assessment in Russia and to establish annual monitoring of such losses. ■

[7]The outliers in North Ossetia for strong winds and heavy precipitation require additional confirmation of the reliability of statistical data on the number of extremes

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