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Climate-Induced Fire Hazard in Forests in the Volga Federal District of European Russia during 1992–2020

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Abstract: This paper shows the relevance of the problem of fire hazard in the forests of the Volga Federal District (VFD) of European Russia. The Nesterov index and the Selyaninov hydrothermal coefficient (*HTC*) are considered as indicators of fire hazard. The changes in climatic conditions in the VFD during 1955–2018 are shown; a trend towards warming and an increase in aridity in the study region were revealed. The repeatability of various fire hazard classes from May to September was calculated using the Nesterov method. It is shown that in July, the most dangerous situation was in the south of the VFD, where the repeatability of class IV fire hazard reached 27%. Using the *HTC* index, the degree of aridity of the district in the summer period was estimated. The frequency of the most arid conditions (*HTC* < 0.5) increases from the north to the south of the district, from 6% (Kirov Region) to 47% (Orenburg Region). Using the *TT* index, the potential thunderstorm danger in the VFD was assessed. With the help of the constructed maps, the hotspots of the most probable occurrence of thunderstorms were detected. The use of Rosstat data on the number of forest fires from 1992 to 2020 made it possible to consider the spatiotemporal distribution of forest fires in 14 administrative regions of the VFD. The distribution of the number of fires by the regions is shown depending on their forest cover and season. The peak of the number of fires was revealed in 2010, when the entire territory of the study region was covered by a severe drought, as a result of which the area of forests covered by fire increased many times over. In recent years (since 2017), there has been an increase in the area of burned forest due to the active phase of climate warming.

Keywords: fire; fire hazard; climate warming; atmospheric drought; thunderstorm; forest cover

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1. Introduction

In recent years, the fire hazard of forests has increased due to the ongoing warming of the climate. Every year in the summer, forest fires occur in many countries, which cause great material and environmental damage to the affected territories. In every fire, there are losses of wood and wildlife. Forest fires rarely approach cities and towns, and there is a threat of destruction by fire of settlements located in forests, and strong smoke in large settlements remote from forests. Summer fires lead to a deterioration in the environmental situation due to an increase in the concentration of carbon monoxide, nitrogen dioxide, suspended particles in the atmosphere, etc.

According to [1], about 200,000 fires are registered annually in the world, in which 40 million hectares of forest burn out, which is 0.1% of the total forest reserves of the planet. According to [2], 400,000 fires annually destroy 0.5% of forests in the world. The estimates given above differ greatly, as they were obtained by different methods.

According to [3], up to 98% of fires in the populated regions of Russia are caused by humans; in remote northern regions, summer thunderstorms are to blame in 50% of cases.

It is noted in [4] that the peak of thunderstorm activity occurs in July, so the maximum number of forest fires occurs in summer. Fires caused by thunderstorms, on average, account for 10% of the total number of forest fires in Russia. At the same time, according to [5], for certain areas (for example, the north of Krasnoyarsk Region in Siberia), the share of fires from thunderstorms can be 90%. The largest share of fires caused by lightning in the total number of fires occurs in the latitude interval 60–65° N, which is about 39%. At higher latitudes, it decreases along with a significant weakening of thunderstorm activity. At the latitudes 65–70° N, the proportion of fires caused by lightning in relation to the total number of fires is about 21% [6].

Forest fires are not only a disaster for the local population but also create an additional source of emissions of greenhouse gases and aerosols into the atmosphere. About 30% of the content of tropospheric ozone, carbon monoxide, and carbon dioxide in the atmosphere is due to the contribution of forest fires. Associated with forest fires, aerosol emissions into the atmosphere can have a significant impact on the microphysical and optical characteristics of the cloud cover and, consequently, on the climate [7]. The thawing of permafrost caused by forest fires leads to significant changes in the soil temperature and moisture regime and, accordingly, to a change in the soil carbon reserve (or the soil carbon reservoir) in boreal forest ecosystems [7].

A number of studies have been devoted to the impact of climate change on forest fires [8–10]. These works, in particular, show an increase in the number of fires in the United States and Canada, caused by climate warming.

The fire hazard situation in forests occurs in dry and hot weather. The danger increases with an increase in the duration of such weather conditions. The relevant meteorological conditions are necessary but not sufficient for the occurrence of a forest fire. For the occurrence and development of a fire, two more conditions are required: the presence of combustible materials (dry mass of plants in any tiers of the forest ecosystem) and the presence of a fire source (fire).

Meteorological parameters are an important factor in the fire hazard of forests. The main ones are air temperature and humidity, wind speed and direction, streams of radiant energy, amount and intensity of precipitation, soil temperature and moisture, etc. As a rule, these are data from meteorological stations or satellite observations.

With increased meteorological fire danger, forest fire most often occurs through the fault of a person when carelessly handling fire in the forest or from thunderstorms. Forest fire from thunderstorms depends on the meteorological conditions of their appearance, and near settlements, the source of fire due to human fault always exists. The problem of predicting the degree of the fire hazard of forests due to environmental (drought, lightning discharges) and anthropogenic reasons is very relevant [11,12]. This paper considers the meteorological conditions of the forest's predisposition to fire and the dynamics of forest fires in the Volga Federal District (VFD) of European Russia in 1992–2020.

2. Study Region

The Volga Federal District (1,038,000 km^2) occupies about 6% of Russia; the population of the district (28.84 million inhabitants) is about 22%. It is one of the most densely populated regions of the country. The district includes the following 14 administrative regions (Figure 1).

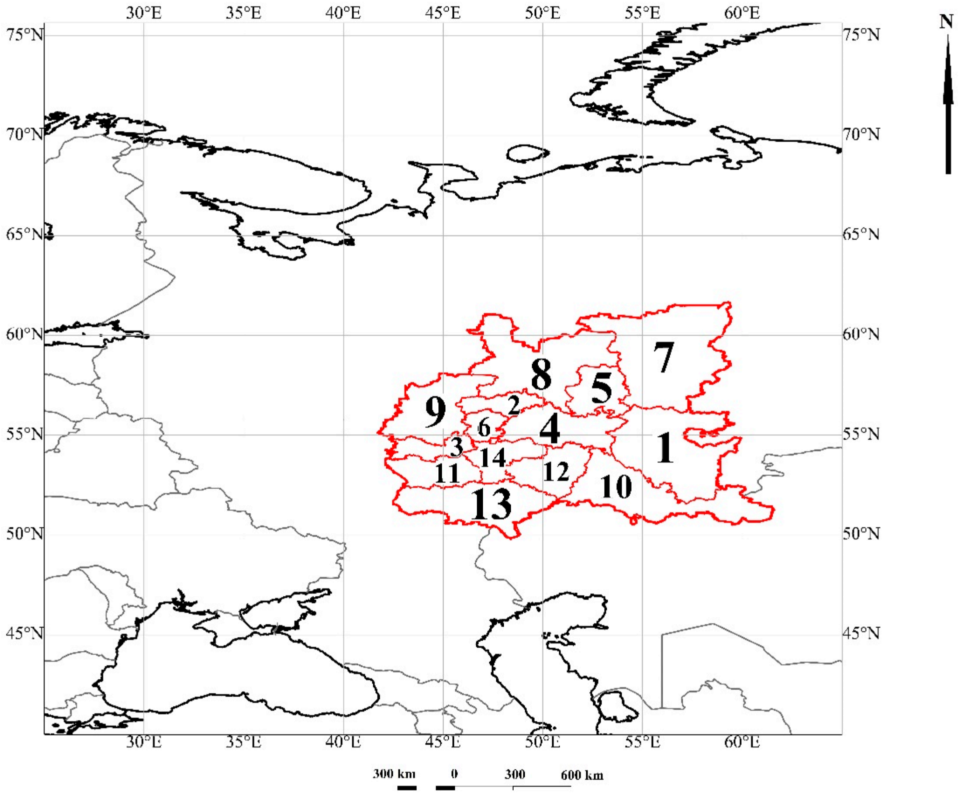

Figure 1. The administrative regions of the Volga Federal District (European Russia): 1—Republic of Bashkortostan; 2—Mari El Republic; 3—Republic of Mordovia; 4—Republic of Tatarstan; 5—Udmurt Republic; 6—Chuvash Republic; 7—Perm Region; 8—Kirov Region; 9—Nizhny Novgorod Region; 10—Orenburg Region; 11—Penza Region; 12—Samara Region; 13—Saratov Region; 14—Ulyanovsk Region.

The Volga Federal District is distinguished by a wide variety of landscape zones: the landscape zones from taiga to semi-deserts are presented. In the direction from north to south, the following zonal types of ecosystems replace each other: dark coniferous middle taiga forests; dark coniferous southern taiga forests with elements of oak; coniferous-deciduous forests; meadow steppes; real steppes; and desert steppes.

3. Materials and Methods

Information on the number of fires in forests compiled by Federal Forestry Agency of Russia and presented on the Rosstat website http://www.fedstat.ru (accessed on 15 April 2022) was used as source material. Data of the observations at meteorological stations on air temperature, humidity, and precipitation were obtained from www.meteo.ru (accessed on 12 April 2022). According to [4], the prerequisites for large forest fires in Russia are a winter with no-deep snow cover and a long period without rainfall (15–20 days) with a high average daily air temperature and low relative air humidity.

Forest fires begin almost immediately after the snow cover melts in spring, if dry weather sets in. There are tracking systems abroad for meteorological conditions that create a risk of forest fires. For example, Canada uses a forest fire hazard tracking system—the Canadian Forest Fire Weather Index (FWI); in the USA—the National Fire Danger Rating System (NFDRS); in Australia—the Fire Danger Rating System (FDRS), etc. Forest fire hazard detection systems and early measures taken contribute to a reduction in forest fires.

In Russia, the Nesterov index (State Standard GOST R 22.1.09-99, 2000) is used to assess the burnability of forests depending on the meteorological conditions. To assess fire hazard in forests, a comprehensive index of fire hazard (G, the Nesterov index [13]) is used. It is calculated according to the formula:

$$G = \sum_{i=1}^{n} T_i d_i, \quad d_i = T_i - r_i, \tag{1}$$

where T_i is the air temperature (°C) at 12:00 local time, r_i is the dew point at 12:00 local time (°C), d_i is the dew point deficit, n is the number of days since any last rain, and i is the serial number of a day. Summation is carried out for those days when daily precipitation (P) does not exceed 3 mm. At $P > 3$ mm, $G = 0$. Conditions with $G < 300$ (mode I) are considered not fire hazardous; in the ranges of 300–1000, 1000–4000, 4000–10,000, and >10,000 are modes with low (mode II), moderate (mode III), high (mode IV), and extreme (mode V) levels of fire hazard, respectively [13]. Fires occur, as a rule, under modes III+.

In [14], a statistical relationship between the number of forest fires and the number of days belonging to fire classes III and IV in the territory of the Middle Urals was revealed. The correlation coefficient between the number of forest fires and the number of days with a high degree of fire hazard in the summer months reached a value of 0.8. In addition, to assess the aridity of European Russia, the hydrothermal coefficient (HTC) of Selyaninov is widely used:

$$HTC = 10P/\sum T, \tag{2}$$

where P is the sum of precipitation (mm) for the period with air temperatures above 10 °C; ΣT is the sum of air temperatures (°C) for the same time. It is generally accepted [15]: $HTC < 0.5$ is very dry; $0.5 < HTC < 1.0$ is not enough moisture; $1.0 < HTC < 2.0$ is sufficient moisture; and $HTC > 2$ is waterlogging.

Abroad of Russia, the Nesterov index is almost not used. In many countries, the KBDI, or Keetch-Byram Drought Index [16], is used to assess the potential risk of forest fires. To calculate the value of the KBDI index for a given day, it is necessary to know the annual precipitation in a given area (climate characteristic), the maximum air temperature during the previous day, and the precipitation for the same day. It was shown [17] that, in the forests of Siberia, a fire hazard situation at $HTC \leq 0.4$ was observed with a probability of 56–72%.

The most informative characteristic of the occurrence of a lightning discharge is the difference between the temperature of a particle raised wet adiabatically from a level of 850 to 500 hPa and the actual air temperature at the upper level. Using this regularity allows to introduce the so-called thunderstorm index. This index determines the possibility of realizing such meteorological conditions under which a lightning electrical discharge is likely. To assess the potential thunderstorm danger, the authors used the Total totals index. It is the air temperature difference between 850 (near-surface) and 500 hPa (mid-troposphere) (gradient level) plus a moisture content index between 850 and 500 hPa. The data source was an ERA5 reanalysis (ECMWF-European Center for Medium-Range Weather Forecasts). The Total totals index (TT) is calculated as follows from Equation (3):

$$TT = (T850 - T500) + (Td850 - T500) = T850 + Td850 - 2(T500), \tag{3}$$

where T is the air temperature and Td is the dew point temperature in °C at the indicated pressure level (hPa). This variable gives an idea of the likelihood of a thunderstorm and its strength using a vertical air temperature and air humidity gradient. The values of this index indicate the following:

<44 K: Thunderstorms unlikely;
44–50 K: Thunderstorms likely;
51–52 K: Sporadic severe thunderstorms;
53–56 K: Severe thunderstorms scattered around;
56–60 K: Severe thunderstorms are more likely scattered.

4. Results and Discussion

The conditions for the formation of modern climate change both in the Northern Hemisphere and the study region were considered earlier in the author's works [18,19]. An assessment of the role of atmospheric circulation in the variability of the air temperature and humidity regime of the Volga Federal District was given. To identify the main patterns in climate change in the Volga Federal District over the past decades, we consider the course of the annual average air temperature (AAAT) averaged over the Volga Federal District for 1955–2018 and two sub-periods (1955–1999 and 1999–2018) (Table 1).

Table 1. Air temperature regime in the Volga Federal District during 1955–2018.

(Sub)-Period	Mean, °C	MSD, °C	Maximum, °C	Minimum, °C
1955–2018	3.49	1.04	5.49 (1995)	0.55 (1969)
1955–1999	3.14	1.00	5.49 (1995)	0.55 (1969)
1999–2018	4.34	0.47	5.33 (2008)	3.58 (2011)

As can be seen from Table 1, at the beginning of the 21st century, there was a significant "jump" in the average air temperature (by 1.2 °C) while the value of interannual temperature variability decreased by a half, and the minimum value of AAAT increased sharply from 0.55 to 3.58 °C. All this testifies to a cardinal change in the thermal regime of the study region at the turn of the century, which provides a higher background of forest fire hazard.

Analysis of the climatic indicators in the Volga Federal District according to data from 183 meteorological stations for 1966–2018 showed that during the year, the air temperature increased at a rate of 0.32–0.53 °C over 10 years. The highest rate of warming was observed in January (0.53 to 1.25 °C over 10 years); in July, the air temperature increase was less noticeable than in January: in the district, the rate varies from 0.24 to 0.56 °C over 10 years. Precipitation in the region increased slightly (average rate of 9.6 mm over 10 years), and in the south-east (the city of Orenburg, the administrative center of Orenburg Region), it even decreased at a rate of −2.9 mm over 10 years.

At the same time, according to [18], the annual sum of average daily air temperatures above 10 °C grew across the study region from north-east to south-west at a rate of 45 to 120 °C over 10 years. The number of days with an average daily air temperature above 10 °C also increased (from 2.5 to 4.5 days over 10 years). These data indicate a noticeable warming of the climate in the Volga Federal District with a slight increase in precipitation (humidity). All this creates the preconditions for an increased forest fire hazard.

Calculations of the frequency of occurrence of the index of flammability by the hazard class show that in March and November, throughout the entire territory of the district under consideration, forest flammability is absent or low. The frequency of class 1 (the flammability index G is in the range of 0–300) at this time varies across the VFD in March from 87.1% (the south of the VFD) to 100% (the north-east of the VFD), in November–from 69.1% (the east of the Republic of Bashkortostan, see Figure 1) up to 100% (the north-east of the VFD). However, starting from April, the frequency of the G index of this class decreases sharply and reaches its minimum of 11.9–45.1% in July (the north-east of the VFD). Moreover, the lowest values, as expected, were observed in the south of the study region. During the warm period (May–September), the frequency of fire classes II and III increases significantly (G changes from 301 to 4000), when the fire becomes medium and high. The total frequency of these classes fluctuates throughout the region in July (maximum) from 54% (the north-east) to 67% (the central part of the region). Thus, the frequency of hazard class IV (G = 4001–10,000) in May–September reaches its maximum in the south of the Volga Federal District (May, 26.6%) and its minimum in the north (September, 0.0%). At the same time, the highest frequency of occurrence of this class of fire, as a rule, is observed in May and in the southern part of the district. Extreme flammability increases markedly from north to south. So, if in the north of the Volga Federal District this class of flammability practically did not manifest itself, then in Orenburg Region (see Figure 1), the frequency of occurrence of an emergency can reach 16%. *HTC*, and the Nesterov index, is an important indicator of fire danger in forests. Its distribution over the district in the period May–September is as follows.

The increase in the values of the *HTC* during the growing season (May–August) occurs from the south to the north-east of the territory under consideration. The highest values are observed in the north-east of the VFDt (Perm Region, see Figure 1) and the lowest in the south (Orenburg Region, see Figure 1).

The repeatability of the conditions "arid" and "insufficiently humid" ($0.5 \leq HTC \leq 1$) in May is 20–50%. The frequency of excess moisture ($HTC > 1$) in May varies from 13.2% in the south of the VFD (Saratov Region and Samara Region, see Figure 1) to 49.1% in the north-east of the study region (Perm Region, see Figure 1).

In June, very dry conditions ($HTC < 0.5$) are observed in Orenburg Region (up to 54.7%); in the rest of the territory, up to 28.3% from 15.7%. Arid and insufficiently humid conditions in June are repeated in the range of 18–40%. The frequency of excessive moisture in June varies from 5–15% in the south of the study region (Orenburg Region, see Figure 1) to 77.4% in the north-east of the VFD (Perm Region, see Figure 1).

In July, very dry conditions have a repeatability of up to 47.2% (Orenburg Region) from 5.7% (Kirov Region, see Figure 1) and in the rest of the territory, 10–25%. The repeatability of the conditions "dry" and "not wet enough" in July is 20–50%. The frequency of excessive moisture in July varies from 9.4% in the south of the Volga Federal District (Saratov Region) to 66% in the north-east of the region (Perm Region, see Figure 1).

In August, very dry conditions are observed in Orenburg Region with a maximum repeatability of 71.7%; as it moves to the north-east of the district, a decrease occurs. In most of the territory, the frequency of droughts is 6–40%. The frequency of conditions "dry" and "not wet enough" in August is 30–50%; only in the north-east do the minimum values reach 17%. Excess moisture in August varies from 5.7% in the south of the VFD (Orenburg Region) to 77.4% in its north-east (Perm Region). The authors also obtained high correlation coefficients between the Budyko and *HTC* dryness indices (correlation coefficients exceed 0.9), which allows to conclude that the correlation between the *G* and *HTC* indices is also high and reliable.

Let us consider the actual data on the distribution of forest fires in the Volga Federal District in 1992–2020. According to Rosstat statistics, during this period, 2683 forest fires per annum occurred in the Volga Federal District, which were unevenly distributed in the administrative regions of the district. Figure 2 shows the annual average number of forest fires in the regions of the Volga Federal District. As can be seen from Figure 2, most forest fires occurred in Nizhny Novgorod Region (692); with the least occurring in Chuvash Republic (49). In addition, significant interannual variability in fires was observed (Figure 3). The maximum number of fires was registered in 2010 (8183), which arose due to the abnormally high air temperature and drought established in the summer of 2010 in European Russia under the influence of a powerful high blocking anticyclone. So, in July, the deviation in the air temperature from the norm (°C) in the administrative regions of the Volga Federal District ranged from 4.0 to 7.0 °C. The hydrothermal coefficient varied from 0.01 to 0.36 [20].

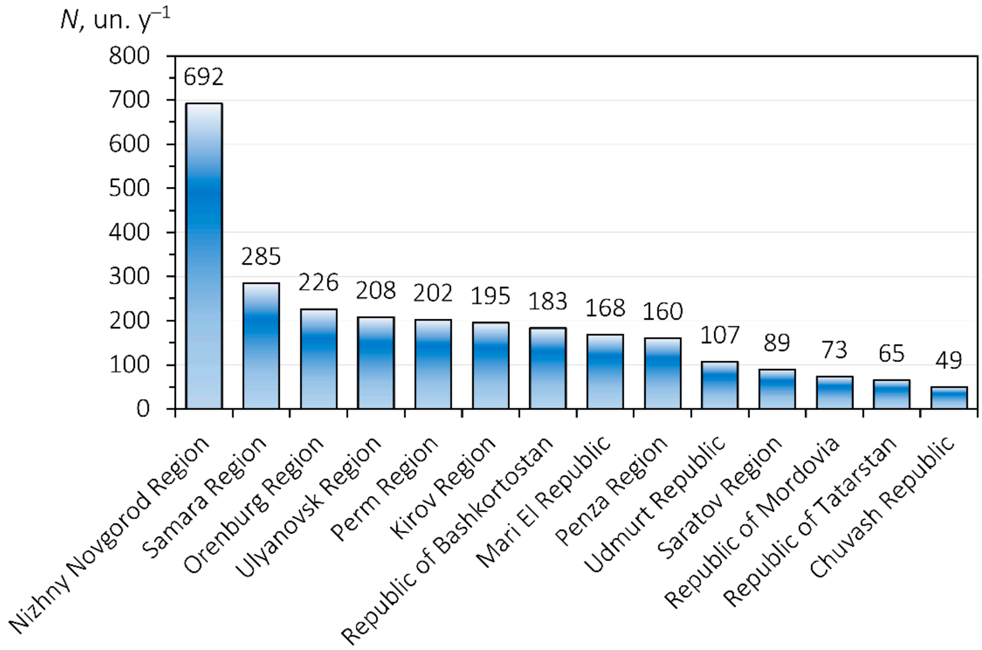

Figure 2. The number of forest fires per annum (N, averaged for 1992–2020) by the administrative regions of the Volga Federal District (see Figure 1).

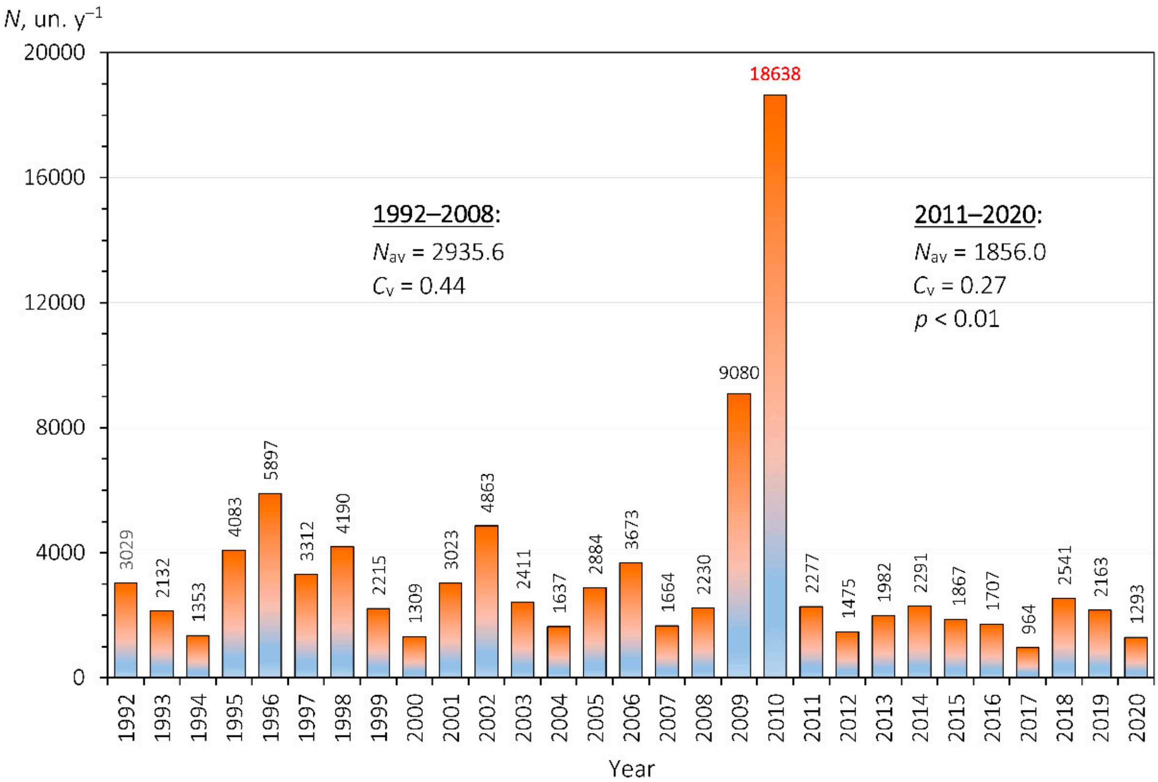

Figure 3. The number of forest fires per annum (N) in the Volga Federal District during 1992–2020. N_{av}—the average value of N for the corresponding observation period; C_v—the coefficient of variation of N; p—the probability of a statistically significant difference between the averages of 1992–2008 and 2011–2020.

The distribution of forest fires in extreme 2010 by the administrative regions of the Volga Federal District is depicted in Figure 4. The largest number of forest fires was in

Nizhny Novgorod Region (1367), and the smallest number in the Republic of Tatarstan (158); that is, a difference of 8.7 times.

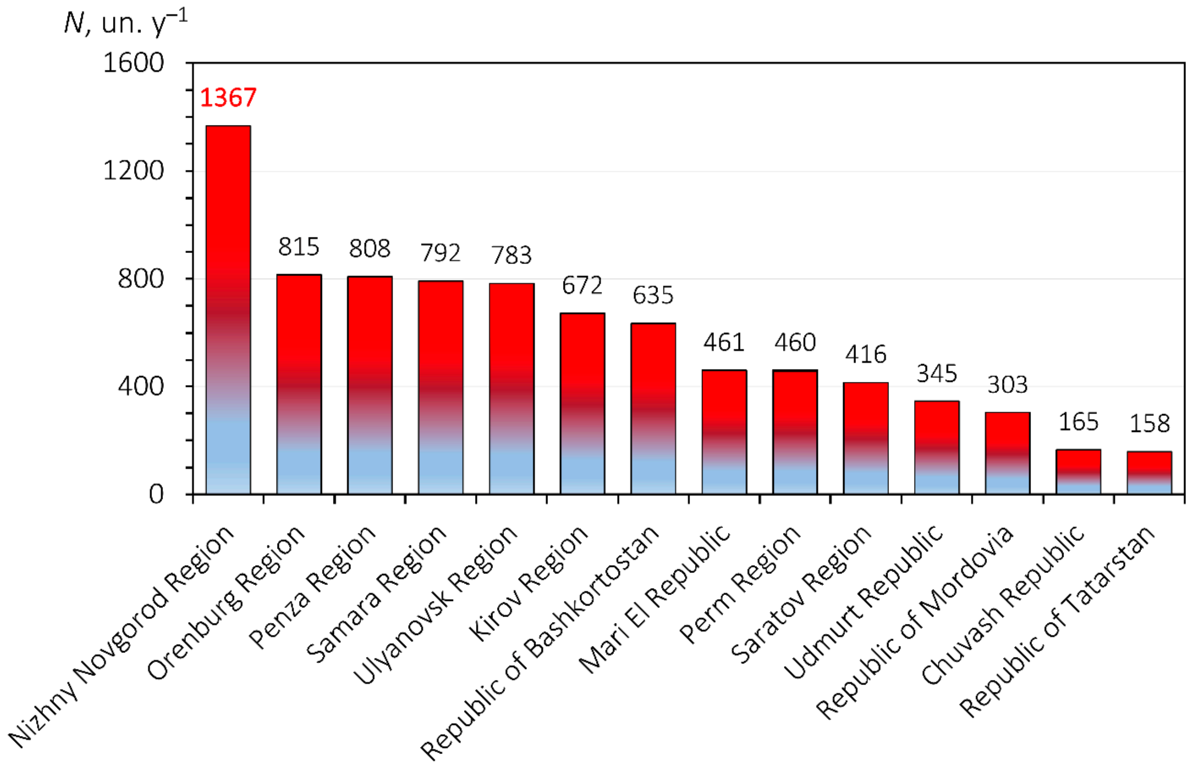

Figure 4. The number of forest fires (*N*) in 2010 by the administrative regions of the Volga Federal District (see Figure 1).

It should be noted that the administrative regions of the Volga Federal District have different areas occupied by forests. Therefore, for a correct understanding of the problem under study, Table 2 provides data on both their forest cover area and the number of forest fires in 2010 per 100 km^2 of forest cover area (*NF*2010) and the average value of forest fires per 100 km^2 of forest cover area (*NF*) for the period 2009–2020.

Table 2. Forest cover, *NF*, and *NF*2010 within the administrative regions of the Volga Federal District (see Figure 1).

Administrative Region	Total Area, km^2	Forest Cover Area, %	Forest Cover Area, km^2	*NF*	*NF*2010
Republic of Bashkortostan	143,600	39.9	57,296	0.32	1.11
Mari El Republic	23,200	56.0	12,992	1.29	3.55
Republic of Mordovia	26,200	27.0	7074	1.03	4.28
Republic of Tatarstan	67,850	17.5	11,900	0.54	1.33
Udmurt Republic	42,100	46.1	19,408	0.55	1.78
Chuvash Republic	18,300	32.3	5911	0.83	2.84
Perm Region	160,600	71.5	114,829	0.18	0.40
Kirov Region	120,800	62.5	75,500	0.26	0.89
Nizhny Novgorod Region	74,800	48.0	35,904	1.93	3.81
Orenburg Region	124,000	4.7	5828	3.87	13.98
Penza Region	43,200	20.6	8899	1.79	9.08
Samara Region	53,600	12.8	6861	4.15	11.54
Saratov Region	100,200	6.3	6313	1.40	6.59
Ulyanovsk Region	37,300	26.6	9922	2.10	7.89

As can be seen from Table 2, in 2010, the number of fires in the forests of the Volga Federal District was approximately three times higher than the long-term average. At the same time, the largest number of fires occurred in 2010 in Orenburg Region (14 fires per 100 km^2 of forest cover area), where the most arid conditions were/are observed. In Samara Region, on average, the largest number of forest fires occurred (4.15 fires per 100 km^2 of forest cover area) in 2009–2020.

Naturally, the climatic conditions of the study region determine their uneven distribution over the quarters of the year. So, in the first quarter (January–March), there were almost no forest fires; however, with the disappearance of the snow cover, the dry last year's grass always creates the prerequisites for ignition. In the second quarter (April–June), forest fires occurred most frequently (on average about 800 for 2009–2020) and in the third quarter (July–September), their number was also high (700); the least occurred in the fourth quarter (~100). At the same time, the situation was not always uniform across the administrative regions of the Volga Federal District. Thus, in the Republic of Bashkortostan, Perm Region, and Udmurt Republic (see Figure 1), the largest number of new fires occurred in the third quarter.

Forest fires cause great economic and environmental damage, which is determined by the area of forest land (ha) covered by the fire. Table 3 presents the information by years (for 2009–2020) on forest areas covered by fire for all administrative regions of the Volga Federal District.

Table 3. Forest cover area with fires (ha) by the administrative regions of the Volga Federal District (VFD) (see Figure 1) during 2009–2020.

Administrative Region	Year					
	2009	**2010**	**2011**	**2012**	**2013**	**2014**
VFD as a whole	9374.872	348,454.8	2945.718	2452.583	2382.442	2833.57
Republic of Bashkortostan	1091	8695.1	372.35	1145.77	107.66	167.15
Mari El Republic	391.6	76,350	16.7	20.2	14	56.3
Republic of Mordovia	162	27,853	6.23	4.64	0.54	8.1
Republic of Tatarstan	83.77	167.9	0	0	0	0
Udmurt Republic	20.016	265.7	6.341	1.881	19.156	10.4534
Chuvash Republic	136.9	9826.8	1	0.08		0.87
Perm Region	172.506	25,379.3	884.245	229.19	754.1	352.6512
Kirov Region	443.28	5200.5	1379.17	8.471	833.23	148.14
Nizhny Novgorod Region	549.8	168,770	61.022	19.975	71.946	885.72
Orenburg Region	1884	5419	118.9	933.606	421.26	845.135
Penza Region	1033	4265	37.7	0.31	23.56	161.54
Samara Region	515	5064.5	14.96	65.1	118.59	50.18
Saratov Region	1507	6364	26	11	1	109.7
Ulyanovsk Region	1385	4834	21.1	12.36	17.4	37.63
	2015	**2016**	**2017**	**2018**	**2019**	**2020**
VFD as a whole	6138.67	1867	2351.8	7079.8	8299	14,895
Republic of Bashkortostan	154.29	455	339.6	915.8	2036.4	3618.4
Mari El Republic	55.03	32	21	28.6	59.2	24.7

Table 3. *Cont.*

Administrative Region	Year					
	2015	**2016**	**2017**	**2018**	**2019**	**2020**
Republic of Mordovia	77.64		15.7	15	3207.9	4.3
Republic of Tatarstan	0	0	0	0	0	39.5
Udmurt Republic	2.4703	8	2.4	15	22.9	2.7
Chuvash Republic	0	1	29	0	9.9	183.3
Perm Region	941.762	344	66.1	175	68.8	358.5
Kirov Region	88.6674	83	3.2	14	68.8	34.2
Nizhny Novgorod Region	104.51	28	25.6	126	118.8	204.1
Orenburg Region	594.189	849	1092.2	2093.8	1433.6	3331.7
Penza Region	233.43	11	61.4	171	214.5	353.7
Samara Region	34.36	11	0	35	123.1	100.3
Saratov Region	719.05	20	510.1	1496.4	276.4	5552.1
Ulyanovsk Region	3133.257	25	185.5	1994.2	658.7	1087.5

As can be seen from Table 3, the largest area of forest land covered by fire belongs to Nizhny Novgorod Region (see Figure 1). Many forests were on fire in Mari El Republic. It should be noted that during a severe drought in the summer of 2010, the largest number of fires occurred, which resulted in a multiple increase in the area of forest land covered by fire. In fact, in the Volga Federal District, the area of forest fires (348,455 ha) in the summer of 2010 was two orders of magnitude larger than in other years. In subsequent years (2011–2014), the situation stabilized. The area of forest fires in the VFD amounted to no more than 3000 hectares; however, from 2017 to 2020, there has been a steady increase in fire areas (Figure 5).

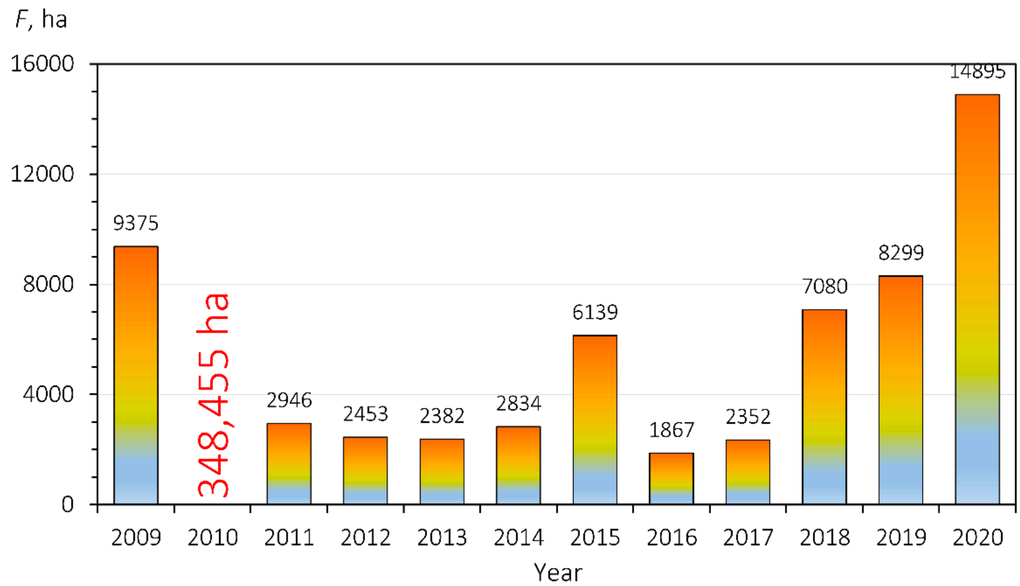

Figure 5. The total annual area of burned forest (*F*) in the Volga Federal District during 2009–2020.

An analysis of the thunderstorm index was performed. Maps of the thunderstorm index averaged over 1979–2021 show that for the Volga Federal District, in May, the *TT* values in the predominant part of its territory were below 44 K, and only in the south of the region (Saratov Region and Penza Region, see Figure 1), they were *TT* = 44 K.

In June and July, the *TT* throughout the entire Volga Federal District was 44–46 K, and minimum values were noted in the Cis-Ural Region. In August, on the whole, the field of *TT* values is similar, with values lower by 1–2 K (42–44 K, with a maximum in the central part of the Volga Federal District). Starting from September, the *TT* values over the VFD do not exceed 44 K, i.e., thunderstorms are unlikely.

The distribution of the values of the *TT* index over the study region shows a widespread decrease in its values in the warm period (except for May). So, the average (for the VFD) *TT* trend was: in May, +0.1 K over 10 years; in June, −0.1 K over 10 years; in July, −0.2 K over 10 years (with the highest rate of the decrease in the east and south of the VFD, Figure 6); in August, −0.4 K over 10 years (with the highest rate of the decrease in the west of the VFD); and in September, −0.3 K over 10 years (with the highest rate of the decrease in the west of the VFD).

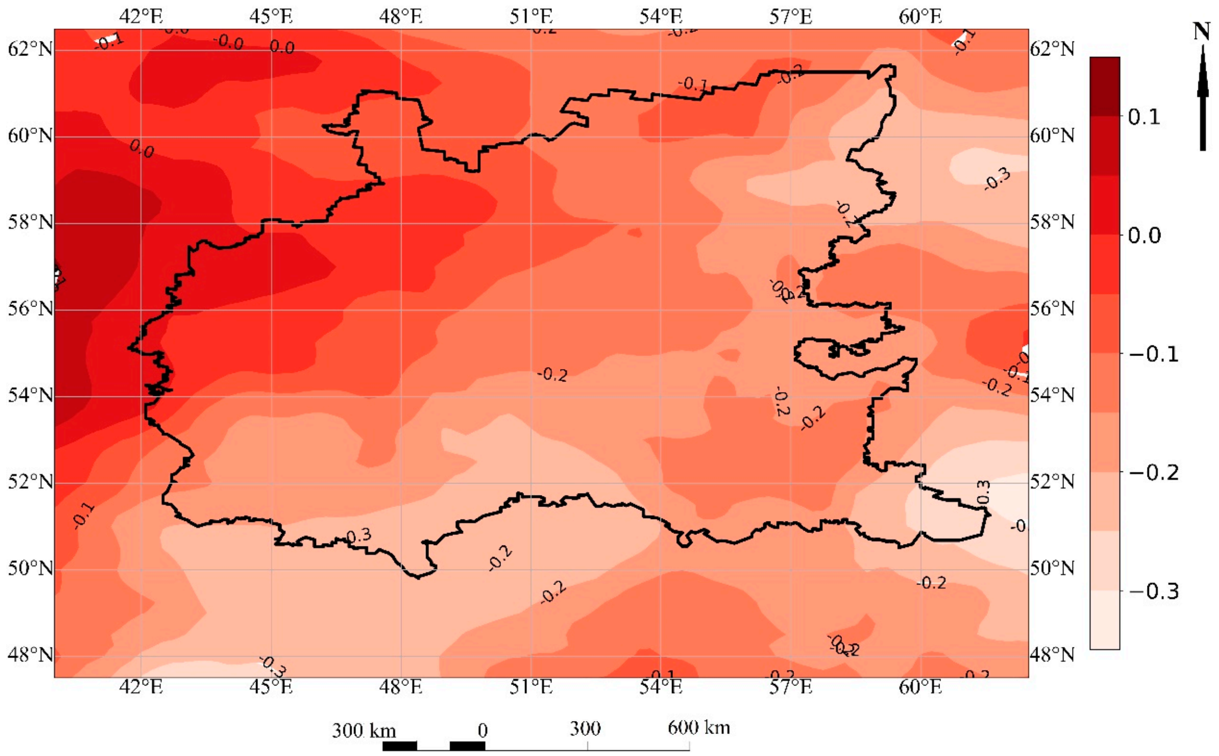

Figure 6. Linear trend of the *TT* index (K per 10 years) in the Volga Federal District (July 1979–2021).

5. Conclusions

(1) The number of forest fires in the Volga Federal District of European Russia experienced significant fluctuations according to the administrative regions and years during 1992–2020.

(2) The greatest hazard to forest lands was a severe drought in the summer of 2010, which resulted in a multiple increase in the area covered by fires and caused great material and environmental damage.

(3) Due to the detected trend of a steady increase in the area of fires in recent years, it is necessary to strengthen measures for the protection of forests and the prevention of forest fire danger.

(4) Trends in the *TT* index, which characterizes thunderstorm danger, indicate its decrease in the warm period of the year.

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