Estimation of climatic predisposition of Tomsk Region to forest fires

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The distribution of climatic parameters over the territory of Tomsk Region is analyzed with respect to the possibility of increasing the efficiency of measures aimed at protection of forests from fires. The new method for determination of fire risks under the conditions of Tomsk Region is considered, which allows one to simplify the process and to lower the corresponding expenses. The climatic predisposition of the territory of the Tomsk Region to forest fires is mapped.

Introduction

Every year forest fires inflict a serious environmental damage. Apart from the direct damage including the losses of flora and fauna, as well as the expenses for reconstruction of forests, there is indirect damage in the form of emission of different products of burning into the atmosphere: aerosols, greenhouse gases, and carcinogenic substances.

The existed discrepancy between the data on the forest fire statistics and forest resources accounts often does not allow one to reliably estimate the cause–effect relations between natural meteorological factors and forest fires. The present-day geophysical technique of the forest fire monitoring is based on the satellite data. The data from the NOAA satellites, having polar sun-synchronic orbits of about 850 km high,[1] are successfully used in Russia for monitoring the forest burning ability.

In this paper we consider the possibility of increasing the efficiency of the fire-control measures. Studying the effect of meteorological parameters on appearance of forest fires makes it possible to do this indirectly through the complex meteorological coefficients and additional techniques for estimation of the fire danger for forests in Tomsk Region. The mapping of the territory of Tomsk Region by its climatic-natural predisposition to forest fires has been carried out.

Earlier we have studied the correlation between meteorological parameters and the appearance of forest fires in Tomsk Region,[2,3] however, the study was limited to only individual meteorological parameters.

1. Probability of appearance of forest fires caused by thunderstorms in Tomsk Region

There exist both anthropogenic and natural reasons for appearance of forest fires. The anthropogenic reasons are: agro-industrial activity near forests, for example, wood-felling, quarrying, tillage, etc. Natural causes of forest fires are related, as a rule, with thunderstorms. Let us estimate the probability of forest fires caused by thunderstorms in Tomsk Region.

Statistical data on such forest fires are ambiguous. Some papers state that from 35 to 50% of annually mean forest fires in Tomsk Region are caused by thunderstorms.[4,5]

In order to estimate the quantity of the thunderstorm forest fires in Tomsk Region during the period 1995–2002, we compared the dates with thunderstorms and the dates of appearance of forest fires. We assumed that all forest fires observed in a thunderstorm day or the next day were provoked by this thunderstorm. In average, 17 thunderstorm days a year were observed in Tomsk Region in the period under consideration, mean duration of thunderstorms was 29.5 hours. Maximum of the thunderstorm days (21) was observed at the south of Tomsk Region (st. Bakchar), minimum (3) – in the eastern part of the region (st. Belyi Yar). Maximal total duration of thunderstorms was 43.8 hours (st. Pudino), minimal duration was 3 hours (st. Pudino). Mean number of days and mean total duration of thunderstorms during 1995–2002 at different sites in the Tomsk Region are shown in Table 1. We compared the data obtained with the climatic values of the thunderstorm activity, using the data on the thunderstorm activity in Tomsk Region during 1966–1995 from Ref. 6 obtained on the basis of the Scientific-Research Institute of High Voltages of Tomsk Polytechnic University (marked by the asterisk in Table 1).

The data presented in Table 1 show that although the location of fireplaces in distribution of the thunderstorm activity over the territory under study is the same, the quantity of the thunderstorm days and the total duration of thunderstorms decreased as compared to 1966–1995. This points to the lowering of the thunderstorm activity.

In opinion of many authors,[7] when finding the correlation between thunderstorms and the quantity of forest fires, the atmospheric precipitation should be taken into account, because the probability of forest fires caused by thunderstorms, accompanied by precipitation less than 2 mm, is significantly greater.

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Table 1. Many-year mean characteristics of thunderstorm activity in Tomsk Region

Meteostation	1966–1995*		1995–2002	
	Number of days with thunderstorm	Duration, hours	Number of days with thunderstorm	Duration, hours
Bakchar	26	50	21	30.2
Baturino	21	40	17	33
Belyj Yar	18	25	3	3
Kozhevnikovo	23	50	20	25
Parabel	19	31	20	36.8
Pervomajskoe	24	39	18	35.6
Pudino	22	43	18	43.8
Stepanovka	22	43	20	40.4
Teguldet	20	37	13	24.6
Tomsk	22	34	17	23

Taking into account precipitation, the maximal possible probability of forest fires due to thunderstorms in Tomsk Region is equal, on the average, to 8.5%. The distribution of thunderstorms over the region is nonuniform. The highest probability of thunderstorms is observed at st. Parabel (20.8%), the lowest – at st. Belyi Yar (1.6%).

The calculation results are mapped in Fig. 1. They point to a higher probability of forest fires caused by thunderstorms in the northwest as compared to the southeast. Such probability distribution can be the evidence of the fact that the appearance of forest fires in the southeast part of the Tomsk Region is connected with anthropogenic factors (work of different gears in forest, closeness to large settlements, etc.), rather than with the natural factor – thunderstorm. The probability of forest fires attributed to thunderstorms in the northwest part is higher, however, thunderstorms are not the main source of forest fires there as well.

Thunderstorms are not the only natural factor favoring the forest fires. A certain combination of meteorological parameters, such as the temperature and humidity of air, precipitation, etc., which will be considered below, strongly affect their appearance.

2. Finding of fire danger from complex meteorological coefficients

There are several criteria for determination of the fire danger in forests based on meteorological indices, which relate the forest burning ability and the temperature, precipitation, wind force, etc. The fire danger calculation using the hydrothermal V.G. Nesterov fire danger coefficient (Nesterov FDC) is used by the Forest Service of the Russian Federation. The coefficient was introduced in 1949 and then was added by N.P. Kurbatskii.[8] It is a cumulative sum of the products of air temperature and humidity deficiency (represented through the difference between the air temperature and dew point temperature). It is calculated by the following formula:

$$\mathrm{FDC}_n = \sum_{J=1}^{n} t_J (t_J - \tau_J), \qquad (1)$$

where FDC is the fire danger coefficient for every day with increasing sum, n is the quantity of days free of precipitation or with precipitation less than 2.5 mm, t is air temperature for the period closest to 1 p.m. of the local time, τ is the dew point temperature at the same period.

The Nesterov FDC is a dimensionless parameter; its numerical value serves to determine the class of the forest fire danger and, correspondingly, to regulate the forest-fire service operation.

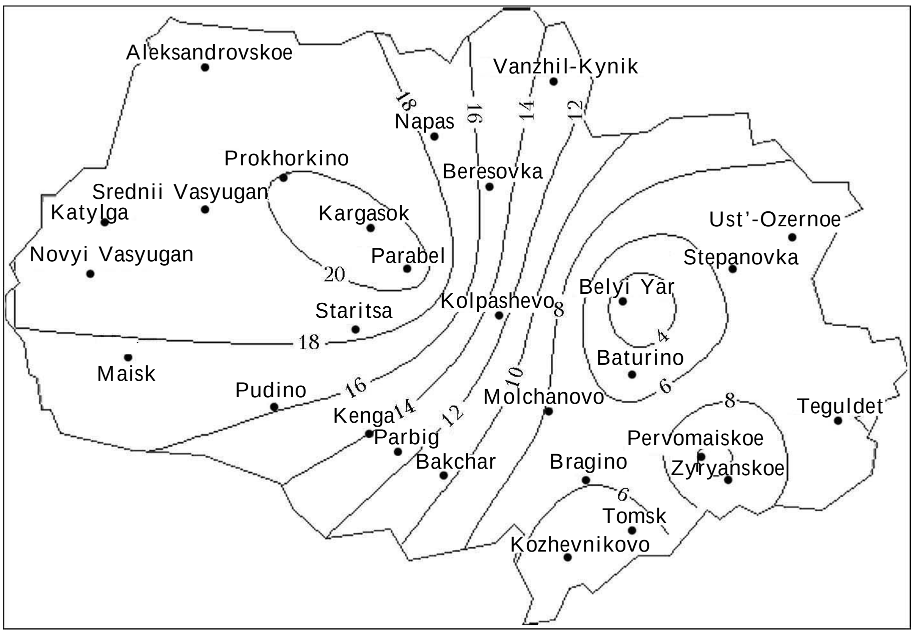

Fig. 1. Maximal possible probability of appearance of forest fires due to thunderstorms in Tomsk Region, %.

To determine the fire danger at the territory of Tomsk Region, the forest protection service uses the all-Russian scale of the fire danger.[9]

The many-year mean quantity of forest fires and the values of the Nesterov FDC are shown in Fig. 2*a*. The behavior of the quantity of forest fires in Tomsk Region during 1998–2002 coincides, with rare exception, with the behavior of the Nesterov FDC values, the extreme points coincide in dates of their appearance in the fire-dangerous period.

The maximum values of the Nesterov FDC were observed on May 25 and July 5, just these days the maximal values of the Nesterov FDC were 4280 and 3518 (54 and 31 fireplaces, respectively). The minimal values of the Nesterov FDC were observed in this period on June 5 and September 3 (1200 and 1100, respectively). The decrease of fireplaces (4 and 2, respectively) takes place at the same time. It was revealed, that the all-Russian scale of the Nesterov FDC does not take into account the peculiarities of the fire-dangerous season in Tomsk Region.

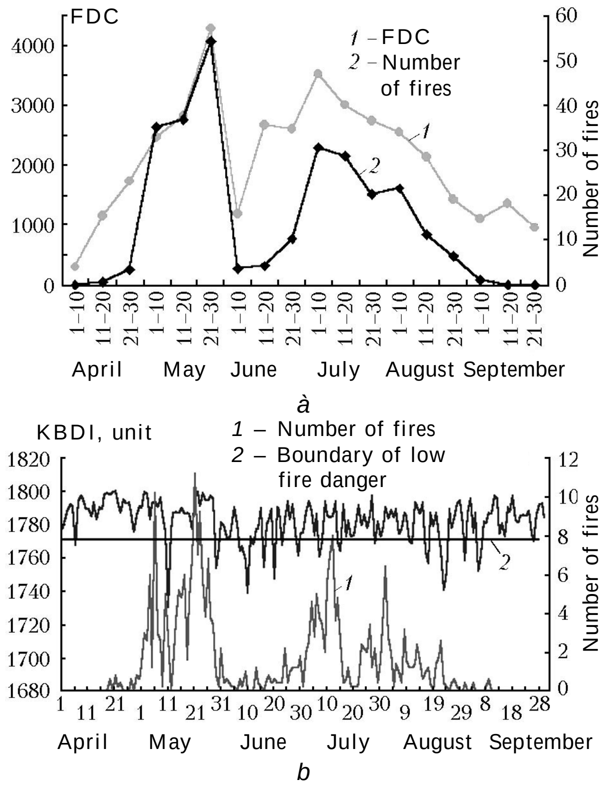

Fig. 2. Many-year mean quantity of forest fires and the values: Nesterov FDC (*a*) and Keetch Byram Drought Index (*b*) in Tomsk Region in fire-dangerous periods 1998–2002.

Based on the revealed empirical dependence of the quantity of fires and the Nesterov FDC value we have developed a local scale of the forest fire danger in Tomsk Region taking into account the suggestions by Kurbatskii (Ref. 10): I class of fire danger corresponds to the period including up to 5% of fires; II class – no more than 15–20%, III class – to 35–40%, and IV class – to 40–45%. Based on the presence of a short break in the appearance of forest fires (Table 2), we divided the fire-dangerous season into spring and summer periods.

Table 2. Local scale of the forest fire danger in Tomsk Region

Period	Class of fire danger			
	I	II	III	IV
Spring	0–800	801–2300	2301–3500	> 3500
Summer	0–1100	1101–1600	1601–3100	> 3100

The Keetch Byram Drought Index[11] (KBDI) is successfully used for determination of the fire danger degree by the United administration of forest fires in East Kalimantan (Indonesia).

Calculation of the index is based on the property of soil to retain water against the earth gravity called the least, or field water capacity. The field water capacity increased by 10 times gives the upper limit of fire danger degree by KBDI. The field water capacity in East Kalimantan is, on the average, 200 mm, therefore, the fire danger is estimated from 0 to 2000 conventional units. The main advantage of KBDI over other fire danger indices is in the fact that only the today quantity of atmospheric precipitation is needed to calculate it.

The clay and medium-loamy soils (by the soil-forming type) mostly characterize Tomsk Region.[12] The field water capacity of such soils is equal, on the average, to 170–190 mm of the moisture in the one-meter thick layer of soil.[13] Hence, the upper limit of KBDI for Tomsk Region equals to 1800 units. On the whole, the dryness index for Tomsk Region is

$$\text{KBDI} = -10R + 1800, \quad (2)$$

where R is the daily precipitation.

The five-year mean values of KBDI and the number of forest fireplaces are shown in Fig. 2*b*. The behavior of KBDI coincides, with rare exceptions, with the quantity of forest fires during the entire fire-dangerous period. Disagreements are observed in early spring and late fall (in the beginning of April and in the end of September), high values of KBDI are accompanied by a low quantity of forest fires, which can be explained by surplus soil moisture in April due to thawing snow and by appearance of low temperatures in September.

The minimal KBDI during the considered period is equal to 1635 units, and the amplitude of its behavior is 165 units. The reason is that, as distinct from tropics, for which the KBDI was originally calculated, the maximal daily precipitation in Tomsk Region does not exceed 20 mm. This prevents from using the accepted KBDI gradations in the fire danger classification of Tomsk Region. For the methods under study to be representative, they must obey the same requirements that the method of the fire danger classification by the Nesterov FDC. Based on the analysis of results, we have developed the local scale of the fire danger by KBDI. It is shown in Table 3.

Comparison of the both techniques shows their advantages and disadvantages. The distribution of the fire cases over the classes of the fire danger for the period 1998–2002, calculated by two techniques, is shown in Fig. 3. For convenience, the classes of the fire danger calculated by KBDI and Nesterov FDC are presented in the ascending order.

Table 3. Scale of the fire danger by KBDI for Tomsk Region

Numerical scale	Characteristics of the fire danger
0–1771	low (I)
1772–1794	moderate (II)
1795–1799	high (III)
1800	extreme (IV)

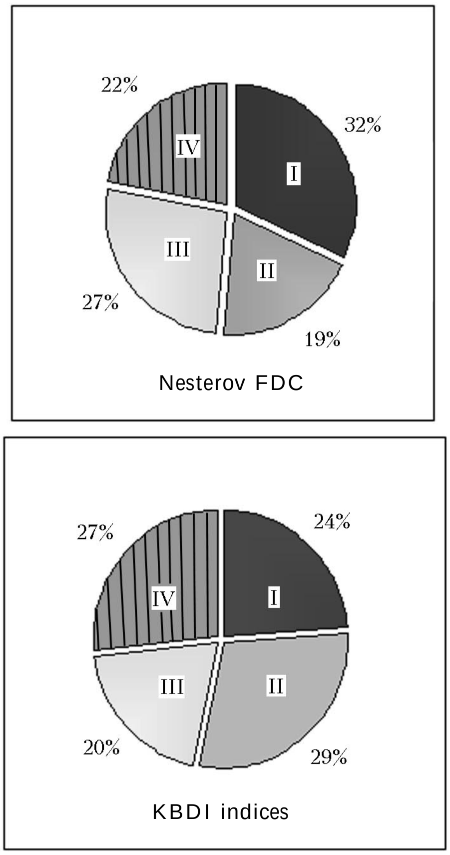

Fig. 3. Quantity of cases in classes of the fire danger upon Nesterov FDC and KBDI in Tomsk Region for 1998–2002.

It is seen that forecasting of the fire danger by KBDI results in greater cases of IV class of the fire danger and less cases of I class than by the Nesterov index. This is connected with different techniques for determination of the indices. In the case of KBDI, at small precipitation, insignificant decrease of the index takes place, which often remains in the same class of the fire danger. In the case of the Nesterov FDC, at precipitation more than 2.5 mm, the index value decreases to zero, that causes a greater number of cases with low fire danger. This can be treated as a disadvantage of the Nesterov FDC, because atmospheric precipitation can cover only a part of the territory, and there exist a risk to underestimate the real fire danger. At the same time, overestimation of cases with extreme fire danger can cause excessive expenses for prevention of forest fires. The advantages of both methods, which make them attractive in prognosis of fire danger in Tomsk Region, are in their calculation simplicity and low cost. In addition, they have no need of extended series of meteorological data.

Thus, we can conclude that the index KBDI as well as the Nesterov FDC can be used for estimation of fire danger in Tomsk Region. Possibly, in future, the KBDI method, new in Russia, after its testing on a longer series of data, will turn to be the method of choice as a cheaper and not less effective.

3. Mapping of Tomsk Region according to climatic predisposition to forest fires

Climatic characteristics and forest fires are usually related by the forest fire index[14] (FFI). Calculation of FFI is based on the values of air temperature and conditions of precipitation during the vegetative period:

$$\mathrm{FFI} = \sum_{i=V_\mathrm{b}}^{V_\mathrm{e}} sd_i \Bigg/ \sum_{i=V_\mathrm{b}}^{V_\mathrm{e}} P_i, \qquad (3)$$

where $sd = 1$ if the daily maximum of air temperature exceeds 25°C and 0 in all other cases, P is the total daily precipitation, V_b is the beginning of the vegetation period, V_e is the end of the vegetation period.

The duration of vegetation period, dates of its beginning and end were determined as a part of a calendar year with a stable daily mean temperature higher than 5°C, because in the majority of cases the active forest vegetation is possible already at this temperature. The dates of stable exceeding by air temperatures of some given limit were determined by the A.V. Fedorov method.[15]

Along with FFI, we studied another climatic characteristics. When mapping the territory, we took into account peculiarities of the territorial distribution of many-year mean meteorological parameters during the fire dangerous period, such as daily minimal humidity of air (W_a), total precipitation for the vegetation period (Q_pr), the Nesterov hydrothermal coefficient, the dryness index, the quantity of temperatures exceeding 25°C ($t_\mathrm{a} \geq 25$°C), and the forest fire index. In addition, to estimate the state of the underlying surface, we have attracted the data on distribution of soil humidity in Tomsk Region,[12] namely, the specific weight of the superhumidified soils in the total soils of some administrative district (W_soil).

The many-year mean distribution of values of three of six considered climatic parameters over the territory of Tomsk Region during the vegetation period of 1998–2002 is shown in Fig. 4. Almost all aforementioned climatic indices divide the territory of Tomsk Region into two big areas, which can be conventionally marked as "northwest' and "central-east."

The third area (conventionally, "south"), stands out by the sum of maximal air temperatures exceeding 25°C during the period under consideration and by FFI. In addition, it is less superhumidified in comparison with two others.

Fig. 4. Many-year mean distribution of the values of climatic characteristics over the territory of Tomsk Region during the vegetation period: Nesterov FDC (*a*), KBDI (*b*), FFI (*c*).

The distribution of the natural-climatic indices according to these areas is shown in Table 4.

In order to estimate the fire danger degree for the considered territory, we estimated its actual burning ability using the common technique used by the Russian forest service added by recommendations from Ref.16.

To do this, we covered the territory of Tomsk Region by the grid with the area of each cell equal to 100 thousand hectares. After having calculated the annual mean (1998–2002) quantity of forest fires for each cell, we estimated the burning ability. The obtained results show the "south" area to be characterized by high and super-high degree of the burning ability (5.1–20.0 fires / 100 thousand hectares). The "central-east" area is characterized by the moderate and low degrees of the burning ability (0.5–5.0 fires / 100 thousand hectares), and the "northwest" area – by very low degree of the burning ability (less than 0.5 fires / 100 thousand hectares).

Table 4. Distribution of natural-climatic indices over Tomsk Region

Climatic characteristic	Area		
	"northwest"	"central-east"	"south"
W_a, %	> 50	45–50	–
Q_{pr}, mm	> 310	260–310	–
Nesterov FDC	< 1300	1300–1700	–
KBDI	< 1782	1782–1785	–
$T_a \ge 25$°Ñ	1000–1200	1000–1300	> 1300
FFI	0.1–0.14	0.12–0.16	> 0.16
W_{soil}, %	> 75	25–75	10–25

The results of the study are shown in the form of the map diagram (Fig. 5), in which the division into districts upon the degree of natural-climatic predisposition to appearance of forest fire is shown based on the behavior of the climatic parameters, complex meteorological indices of the fire danger of the territory and other natural factors such as the specific weight of the soil superhumidity.

When mapping the Tomsk Region, we did not take into account the climatic distribution of the wind velocity, because Tomsk Region is characterized by small amplitude of the annual behavior and the annual mean velocity of wind. The available data suggest[17] that the amplitude of the annual wind behavior varies within the limits 0.9 to 2.0 m / s and the annual mean values of the wind velocity change from 2.1 to 4.2 m / s. The wind velocity more than 10 m / s was observed for the considered fire-dangerous period, on the average, during 2–5 days. This points to a weak effect of the wind velocity on the fire danger in Tomsk Region.

Conclusion

The conducted analysis of distribution of climatic parameters over the Tomsk Region territory makes it possible to better understand the reasons of forest fires.

The considered new method for forecasting the fire danger using the KBDI index in conditions of Tomsk Region allows one to simplify the process and to decrease the expenses for estimation of the fire danger of the territory. Besides, the KBDI method can be used to estimate the fire danger at all territory of Siberia, as well as the proposed technique for classification the territory by its natural-climatic predisposition to forest fires.

This paper is based on the data on forest fires in Tomsk Region obtained from satellites of the NOAA series during 1998–2002, presented by the Federal institution "Tomsk Administration of Rural Forests" and Main Administration of Civil Defense and Extraordinary Situations of Tomsk Region.

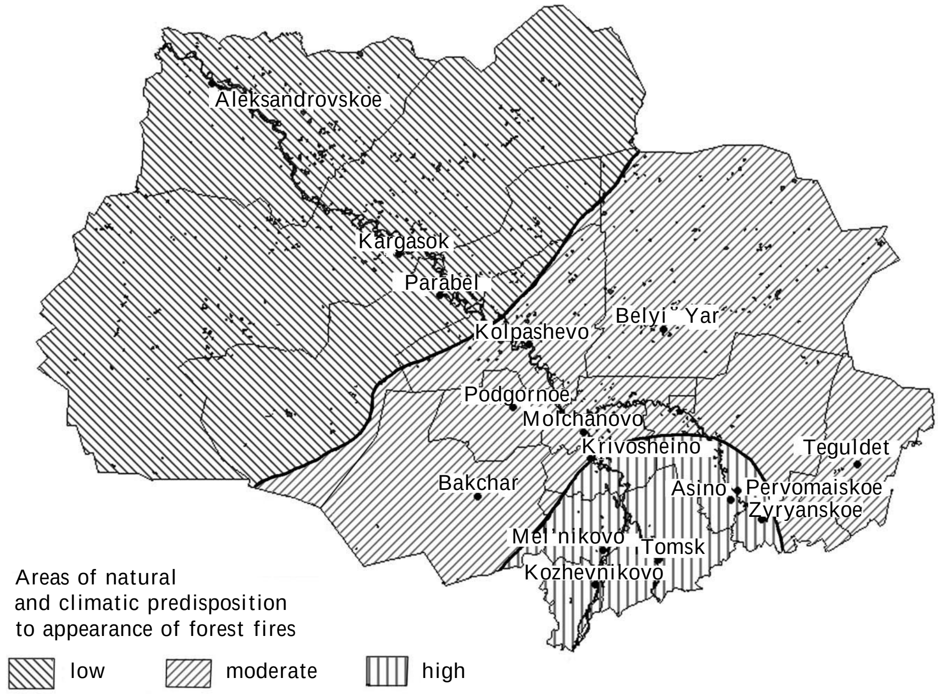

Fig. 5. Classification of the territory of Tomsk Region into districts by its natural-climatic predisposition to forest fires.

Meteorological data were presented by the West-Siberian administration of the Hydrometeorological service.

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