Forest fires environmental impact study

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Abstract. The impact of the toxic components of the pyrolysis products of forest combustible materials, air temperature, and thermal radiation on the environment was studied. The data on the amount of solid particles contained in the smoke of forest fires and controlled fires are presented. The ratio of the mass of solid particles of smoke aerosol and the mass of burnt combustible material for different combustible materials is determined. The data on the toxicity of gases generated during the forest combustible materials burning and their effect on the human body are presented. The specific emissions (emission factors) of substances in a fire are determined and the methodology for their calculation is given. The dynamics of forest burnability in the Krasnoyarsk Territory over the past 48 years and the reasons for the increase in forest area covered by fires are presented. Measures to reduce harmful emissions from forest fires into the atmosphere and to reduce environmental pollution by improving the mechanisms for regulating forest protection activities and preventing the occurrence and extinguishing of forest fires are proposed.

1. Introduction
Krasnoyarsk Territory owns wood resources in the amount of 7.4 billion m³ (coniferous species 80%), which is about 8% of Russia's forest reserves. The annual volume of stem wood harvesting in the region reached 54.5 million m³. The estimated cutting area in the region was used only by 10.3%, and the volume of harvested wood was estimated at 8–8.5 million m³ [1]. As of January 1, 2018, the total forest land area amounted to 158.7 million hectares, of which the forested area is 104.9 million hectares. The total timber stock according to the state forest register is 11.4 billion m³. The share of the forested area of the Russian Federation in global carbon emissions is about 10% [1].

Harvesting of primary wood from felling is approximately 110 million m³, from intermediate felling and thinning - 60 million m³ [2] per year.

One of the most important reasons for the reduction of forest area is natural fires. They are capable of negatively changing and transforming the natural environment, the state of forest biogeocenosis, its further development, trends, and dynamics within a noticeably short time [3]. The problem of combating natural fires is one of the most urgent not only in the forestry sector of the Russian Federation, but also in many other countries, including China, the USA, and France. Moreover, natural fires are a threat not only to the forest and its inhabitants, but also to humans. Hundreds of forest protection experts, as well as people from other areas of activity involved, are engaged in extinguishing and localizing natural fires.
2. Materials and methods

The aim of the research is a theoretical and experimental study of the impact of forest fires on the environment, which will allow us to develop basic requirements for reducing the negative impacts of their harmful and dangerous factors.

In such a case, it is necessary to solve the following tasks: to identify hazardous factors affecting the environment; to develop measures aimed at reducing harmful emissions from forest fires into the atmosphere.

The big problem now is the fight against environmental pollution. With catastrophic speed, huge masses of substances harmful to nature pollute the biosphere. For thousands of years a man has been polluting the atmosphere, but the consequences of using fire, which he used all this period, were not so significant. In recent centuries, with the advent of megacities and the development of science, industrial enterprises, automobiles, tractors, boiler houses, thermal power plants, and other factories polluting the air with harmful substances began to appear [4].

There are three main sources of air pollution: transport, industry, and domestic boiler houses. Industrial production pollutes the air most heavily. Sources of pollution are thermal power plants that emit carbon dioxide and sulfur dioxide together with smoke in the air. Metallurgical enterprises emit phosphorus compounds, hydrogen sulfide, chlorine, ammonia, fluorine, particles and compounds of arsenic and mercury, nitrogen oxides into the air. Because of the burning of hydrocarbon fuels for the needs of modern industry, the operation of transport, heating homes, as well as the combustion of flammable substances during natural fires, the burning and processing of industrial and household waste, harmful gases enter the air.

With forest fires, soot particles, that is, carbon and products of incomplete combustion of wood - a variety of organic substances, which include many harmful compounds with mutagenic and carcinogenic properties enter the air. In the mass of air pollution by man in the first place are carbon monoxide and dioxide. Most of the carbon in fossil fuels of various types is oxidized to carbon dioxide CO2, a smaller part to carbon monoxide CO.

In foreign reviews [5], a large number of various impurities formed during forest fires are indicated. The amount of combustion products of forest combustible materials depends on humidity - with its increase, the yield of nitrogen and carbon dioxide decreases and the yield of water vapor increases [6]. The total yield of gaseous products of forest combustible materials combustion decreases with increasing humidity. With incomplete combustion, in addition, carbon monoxide, hydrogen, and hydrocarbons are released. Forest fires are characterized by incomplete combustion of part of forest combustible materials, the presence of carbon monoxide in the gas environment. The composition of the combustion products is determined by the mass fractions of the chemical elements that make up the compound of the combustible mixture, as well as the temperature and pressure at which combustion occurs.

The chemical composition of wood, bark, leaves, needles, dry grass, and other types of forest combustible materials is known [7], however, since forest combustible materials are rare without mineral impurities, some of them do not burn completely, the combustion conditions can change sharply, and the composition of the fumes can be added to various dusts, the composition of the gaseous environment of forest fire smoke is very complex and variable. There is little data on the amount of particulate matter contained in the smoke of forest fires and controlled fires. Thus, according to the estimates of American researchers [4], the emission of solid particles during guided fires in the southern United States is 8 kg per 1 ton of combustible materials, and during natural fires –26 kg per 1 ton.

The solid particles of the smoke aerosol and the mass of the burned fuel material weight ratio is different. According to experimental data, the combustion of one ton of forest combustible materials 24 kg of particulate matter flows into aerosol. Toxic gases formed during combustion have toxic effect on the human body. Carbon monoxide is the most toxic component of the volatiles produced during the pyrolysis of forest combustible materials. As a product of incomplete combustion of forest combustible materials carbon monoxide is formed as a result of lack of oxygen, which is detected in the fumes released during the combustion in larger or smaller concentrations.
The danger of carbon monoxide lies in the fact that it has neither odour nor colour. When the content of carbon monoxide (sweetdamp) in the air is of 0.1% in humans residing in this atmosphere for 45 min, it causes a slight headache, mild poisoning and as a result nausea and dizziness. If staying in for 45 minutes in the air with a carbon monoxide content of 0.15% -0.2% of a person loses the ability to move and the threat of poisoning appears. When the content of CO in the air is of 0.5% severe poisoning occurs within 15 minutes, and if the contents of it is of 1%, the person loses consciousness and in 1-2 min it can lead to fatal poisoning. The danger lies, first, in the toxic effects of oxygen deficiency on brain tissue, resulting in the weakness, palpitations, breathing disorders. This reduces the focus, decreases ability to think and increases considerably the response time to any external influence. In severe poisoning loss of consciousness followed by death may occur.

A less toxic compound is carbon dioxide. Its air content from 12.1 to 38.2 mg / m³ causes irritation of the upper respiratory tract and eyes. With such a concentration of CO₂, the duration of activity is allowed no more than for one hour. Its concentration equal to 160-200 mg / m³ when inhaled for five to ten minutes can be fatal. When several harmful substances are contained in air at the same time, the sum of the actual concentrations of the ratios of each of them to MAC 1, MAC 2, ..., MACN should not be higher than a unity [4, 6]. The chemical composition of atmospheric air at the earth’s surface is shown in table 1.

| Gas                  | Molecular mass | Volumetric concentration (%) |
|----------------------|----------------|------------------------------|
| Nitrogen             | 28.0134        | 78.084                       |
| Sulphur dioxide      | 64.0628        | from 0 to 0.0001             |
| Helium               | 4.0026         | 0.000524                     |
| Hydrogen             | 2.01594        | 0.00005                      |
| Nitrous oxide        | 44.0128        | 0.00005                      |
| Argon                | 39.9480        | 0.934                        |
| Krypton              | 83.8000        | 0.000114                     |
| Nitrogen dioxide     | 46.0055        | from 0 to 0.000002           |
| Oxygen               | 31.0998        | 20.9476                      |
| Xenon                | 131.3000       | 0.0000087                    |
| Methane              | 16.0430        | 0.0002                       |
| Carbon dioxide       | 44.0099        | 0.0314                       |
| Neon                 | 20.1790        | 0.001818                     |
| Methane              | 16.0430        | 0.0002                       |
| Ozone                | 47.9982        | from 0 to 0.000002 in winter |

The formation of physical and chemical substances that adversely affect people and the environment, or their release into the air for a certain time, is called the pollution emission into the atmosphere.

The emission factor or specific emission of a substance in a natural fire is the ratio:

$$K_a = \frac{m_a}{m_r},$$

(1)

where \(m_r\) is the mass of forest combustible materials per unit of forest area during a natural fire; \(m_a\) is the mass of the component formed during the burning of forest combustible materials on a unit area in the same natural territory;

Index \(a\) varies from 1 to \(N\), where \(N\) is the number of total harmful substances (pollutants) arising from a forest fire.

The coefficient of incomplete burning of forest combustible materials is determined by the formula:
The amount of burned forest combustible materials $m_r$ can be determined by the formula:

$$m_r = m_o - m_n$$  \hspace{1cm} (3)$$

The mass emission of harmful substances of $a$-grade arising from the burning of a unit area covered with forest combustible materials is determined by the expression:

$$m_a = K_a \cdot (m_o - m_n)$$  \hspace{1cm} (4)$$

The emission of heat into the earth’s atmosphere is determined by the formula:

$$Q_p = g \cdot (m_o - m_n),$$  \hspace{1cm} (5)$$

where $g$ is the thermal effect of the combustion of forest combustible materials, $J / kg$.

The coefficient of completeness of combustion is determined by:

$$K = 1 - K_{ht}$$  \hspace{1cm} (6)$$

The total emission of a-heat mass and component for any type of natural fire is determined by:

$$M_{ai} = S_i \cdot K_i \cdot K_{ai} \cdot m_{30};$$  \hspace{1cm} (7)$$

$$Q_{ai} = g_i \cdot k_i \cdot m_{30},$$  \hspace{1cm} (8)$$

where $S_i$ is the forest area covered by the fire; $Q_{ai}$ - heat released during the fire, $J$; $g_i$ is the thermal effect of the combustion of forest combustible materials, $J / kg$; index $i$ is equal to: 1 - corresponds to the parameters of a natural ground fire; 2 - corresponds to the parameters of the top natural fire; 3 - corresponds to the parameters of soil fire.

The average values of the emission factors are presented in table 2.

| Name                                      | The value of $K_a$, kg / kg |
|-------------------------------------------|-----------------------------|
| Carbon dioxide                            | 0.094                       |
| Carbon monoxide (carbonous oxide)         | 0.135                       |
| Soot (elemental carbon) during combustion | 0.0014                      |
| Nitrogen oxide                            | 0.000405                    |
| Smoke (smoldering mode)                   | 0.055                       |
| Smoke (combustion mode)                   | 0.014                       |
| Methane                                   | 0.075                       |
| Ozone                                     | 0.001                       |
| Soot when smoldering                      | 0.011                       |
| Other hydrocarbons                        | 0.011                       |

A constant increase in the forest burning rate using the example of the Krasnoyarsk Territory can be observed. For this, it is enough to analyse the dynamics of forest burnup in the Krasnoyarsk Territory over the past 48 years (figures 1–3).

The reasons for the increase in forest area covered by fires can depend on: a decrease in the frequency of forest aviation due to the small number of air patrolling; a reduction in the number of aerial forest protection workers, as well as an increase in the protected forest area per worker over 180
thousand hectares; difficulties in financing forest protection from the local budget; the transition of forest fires to the category of large fires for the above reasons.

From the data in figure 1 it follows that in recent years, a decrease in the frequency of aerial observation and the number of forest firefighters has not led to an increase in the average number of forest fires and the area covered by them.

![Figure 1](image1.png)

**Figure 1.** Dynamics of reduction in the number of forest firefighters, protected areas, the number of fires, as well as the frequency of aerial observations, where

- Number of firefighters
- Frequency of aerial observations, %
- Number of fires
- Protected area, million ha

At the same time (figure 2), the sizes of burned-out forest areas, average areas of fires, the number of large forest fires and the areas covered by them increased significantly.

![Figure 2](image2.png)

**Figure 2.** Dimensions of burned-out forest areas, average area of fires, the number of LFF (large forest fires) and the areas covered by them, where
Figure 3 presents data on the absorption of oxygen in the fire of natural fires, on emissions of oxide and carbon dioxide.

In absolute terms, in the Krasnoyarsk Territory in 1971–2018, 68.85 million tons of oxygen, 26.76 million tons of dioxide and 40.18 million tons of carbon monoxide were released. At the same time, for 1995–2013 these values amounted to 47.02; 19.4; 29.82 million tons respectively, and for 2003–2018 - 44.65; 17.5; 29.98 million tons. That is, emissions in terms of 1 year doubled. It was established [6] that, on average, 3 kg of forest combustible materials are located on 1 m², while burning 1 kg of forest combustible materials, 0.4 kg of carbon monoxide and other harmful substances are released into the atmosphere and 5.4 kg of air or 1.24 kg of oxygen is absorbed (with the completeness of combustion of forest combustible materials - 50%). Consequently, during the combustion of 1 ha of forests, 12 tons of carbon monoxide and other harmful substances are released into the atmosphere and 37.2 tons of oxygen are absorbed. 2.6 million tons of oxygen are annually destroyed by forest fires in the Krasnoyarsk Territory and 0.83 million tons of toxic gases is released into the atmosphere.

3. Conclusion
Forest fires in boreal pine forests affect carbon balance through the emission of gases and aerosols, as well as effects on ecosystem components. The degree of impact depends on the intensity of combustion, the composition and stock of forest combustible materials.
The elemental composition of aerosols during forest fires is determined by a complex of combustible materials, is stable and does not qualitatively depend on the intensity of the fire. The concentration of elements in aerosols is determined by the intensity of the fire.

During forest fires of different intensities in the pine forest, lichen-green moss releases from 4.8 t/ha to 15.4 t/ha of carbon. The estimated amount of gas-aerosol emissions depending on the fire intensity is from 11.3 t/ha to 35.5 t/ha.

The largest share in carbon-containing gas emissions is accounted for by CO and CO2. (up to 98%) and the remaining gases make up less than 2-5%.

It is required to develop new technologies for extinguishing forest fires, special equipment and tools for their implementation, taking into account the exclusion of damage to the ground cover along the route from the forest fire [7].

To reduce harmful emissions from forest fires into the atmosphere, it is necessary to carry out the following priority works: creating a unified system to combat natural fires; increased local authorities responsibility for the protection of forests, the prevention and extinguishing of natural fires; improving economic mechanisms for regulating forest conservation; preventing the elimination and occurrence of natural fires, as well as material and technical support for this activity; reclamation, development, and exploration of territories occupied by forests in order to reduce the likelihood of natural fires improving the legal framework in order to strengthen the criminal and administrative responsibility of those responsible for natural fires, expanding outreach to the media.

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