Contribution of forest and peat fires to atmospheric pollution in the Irkutsk region

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Abstract. Smoke and toxic combustion products emitted as a result of natural fires are among the most hazardous factors, as they lead to poisoning and death of people, as well as environmental pollution. Only one hectare of a burning forest accounts for 80 to 100 tons of smoke particles and 10-12 tons of a mixture of gases such as carbon monoxide, carbon dioxide, sulfur and nitrogen oxides, acetaldehyde, acetone, acrolein that are emitted into the atmosphere. The smoke of forest fires consists of tar drops, water vapor, gaseous substances and soot. Bulk emissions of ecotoxicants into the atmosphere generated during natural fires make an additional contribution to environmental pollution. The aim of the paper was to assess the contribution of forest and peat fires to atmospheric pollution in the Irkutsk Region. Based on statistical data as well as monitoring the consequences of forest and peat fires, studying procedural documents for investigating and describing fires, we calculated quantitative indicators of burnt natural materials in the territory of the Irkutsk Region for 2011-2018. When comparing pollution indices from stationary sources (the calculation was made according to the annual reports on the state of the environment in the Irkutsk Region) as well as forest and peat fires, it was found that the contribution of forest and peat fires reached 23.0 -9.6%, the average value for 8 years was 16.8%. We found that for the period 2011-2018 as a result of forest and peat fires on average up to 259.12 thousand tons of pollutants were released into the atmosphere annually. Forest and peat fires make a significant contribution to atmospheric pollution in the Irkutsk Region. In addition to atmospheric pollution, other unfavorable environmental consequences are realized. In particular, during peat fires, burning is slow due to the lack of oxygen and fire does not propagate as fast as on the surface, it forms burnt voids and there is a chance of falling into burnt peat. Forest and peat fires lead to the destruction of forests in vast territories and may be one of the possible causes of the catastrophic flood in the Irkutsk Region in June 2019.

1. Introduction
The Irkutsk Region is one of the most developed regions of the Russian Federation. It is called the energy and industrial center of Eastern Siberia. The Irkutsk Region has large reserves of natural resources: there are reserves of black coal, iron, gold, mica, granite, salt, oil, gas, and peat. The presence of significant timber reserves served as the basis for the development of the timber industry on the one hand, and on the other hand, for emergency situations accompanied by uncontrolled bulk emissions of toxic substances, especially in the last five years. Forests of the Irkutsk Region are characterized by high combustibility. A feature of the forest fund of the region is the predominance of fire hazardous coniferous stands (more than 90% of the total area covered by forest). The duration of the fire hazard period can reach maximum of 170 days.
About 130 peat deposits are known in the region. Their total forecast resources are estimated at approximately 0.5-1.0 billion tons. However, commercial extraction of peat is not yet conducted due to the presence of huge reserves of black coal and large tracts of wood resources. Peat was extracted in small volumes only in the 1920s at the Innokentsvsky (Irkutsk-Zhilkinsky) peat deposit, known since the end of the 19th century. It is located in the floodplain of the Irkut river, near the Irkutsk-Sortirovchny railway station. Peat extraction near the station of Innokentyevskaya was conducted during the Civil War, when Irkutsk experienced interruptions in the supply of fuel, coal and wood. In the vicinity of Irkutsk there are also the Topkinskoye (along the Topka river), Plishkinkskoye and Pivovarikhinskoye peat deposits. There are peat deposits in the Zima, Usolye, Zalari, Tulun and Nizhneudinsk Municipalities. Numerous peat bogs are located on the watershed of the Iya, Ikei and Kirei rivers, in the floodplain swamp along the Uk River and the swamp along the Khingui River, as well as in the Tyret, Nukutsk, Bokhan, Kuitun and other municipalities. Peat of almost all known deposits is located directly under the vegetation cover in the form of layers several tens of meters wide and with a thickness of 0.2-2.5 m [1].

Having analyzed the statistical data, we found that in the Irkutsk Region an average of more than 1.3 thousand natural fires occur annually, resulting in tens of thousands of hectares of forests tracts and areas burned out.

Studies [2-9] found that smoke and toxic combustion products emitted as a result of natural fires are among the most hazardous factors, as they lead to poisoning and death of people, as well as environmental pollution. Only one hectare of a burning forest accounts for 80 to 100 tons of smoke particles and 10-12 tons of a mixture of gases such as carbon monoxide, carbon dioxide, sulfur and nitrogen oxides, acetaldehyde, acetone, acrolein that are emitted into the atmosphere. The smoke of forest fires consists of tar drops, water vapor, gaseous substances and soot.

It was found that bulk emissions of ecotoxicants into the atmosphere generated during natural fires make an additional contribution to environmental pollution, which in recent years accounts for more than 10% of the total amount of pollutants entering the atmosphere of the Irkutsk Region from stationary sources of pollution [10,11].

The aim of this study is to assess the contribution of forest and peat fires to atmospheric pollution in the Irkutsk Region.

2. Study objects and methods

The initial data for this study were statistics on forest and peat fires obtained from official sources.

Based on statistical data as well as monitoring the consequences of forest and peat fires, studying procedural documents for investigating and describing fires, we calculated quantitative indicators of burnt natural materials in the territory of the Irkutsk Region for 2011-2018 (Table 1).

Analysis of the data in Table 1 allows us to conclude that for the period from 2011 to 2018 in the Irkutsk Region, on average, the total area of forest and peat fires was about 425.1 thousand ha. As a result of fires, up to 1873.3 thousand tons of natural combustible materials were burnt. The amount of combustion products emitted into the atmosphere of the Irkutsk Region was estimated by the method developed by the authors [11].
Table 1. Quantitative indicators of the consequences of forest and peat fires in the territory of the Irkutsk Region for 2011-2018.

| Year | Total area of fires, thousand ha | Burnt area covered with forest, thousand ha | Burnt area of peat soil and peat, thousand ha | Burnt mass, thousand tons | Combustible forest materials in territories covered by forest, not covered by forest, and steppe territories | Peat soil and peat |
|------|---------------------------------|-------------------------------------------|---------------------------------------------|--------------------------|-----------------------------------------------------------------------------------------------|------------------|
| 2011 | 156.8                           | 121.7                                     | 10.5                                        | 511.5                    | 188.4                                                                                         | 4.6              |
| 2012 | 24.5                            | 20.5                                      | 2.8                                         | 86.1                     | 27.4                                                                                          | 1.1              |
| 2013 | 27.1                            | 24.6                                      | 4.6                                         | 103.3                    | 27.8                                                                                          | 2.1              |
| 2014 | 770.8                           | 679.5                                     | 22.8                                        | 2833.9                   | 817.0                                                                                         | 9.9              |
| 2015 | 395.6                           | 351.6                                     | 20.6                                        | 1476.7                   | 415.4                                                                                         | 9.0              |
| 2016 | 743.9                           | 569.1                                     | 25.0                                        | 2390.2                   | 905.5                                                                                         | 10.9             |
| 2017 | 968.8                           | 503.7                                     | 25.8                                        | 2115.5                   | 1499.8                                                                                        | 11.3             |
| 2018 | 313.3                           | 284.2                                     | 8.9                                         | 1193.6                   | 321.2                                                                                         | 3.9              |
| Average value | 425.1                         | 319.4                                     | 15.1                                        | 1341.5                   | 525.2                                                                                         | 6.6              |

3. Results and discussion

Based on the data on the amount of burnt natural materials and specific emission factors of toxicants per unit of burnt mass [10-12], we determined the amount of pollutants that entered the atmosphere of the region in the period 2011-2018 (Figure 1).

![Figure 1. Mass of pollutants released into the atmosphere as a result of forest and peat fires in the Irkutsk Region for 2011-2018.](image)

When comparing pollution indices from stationary sources (the calculation was made according to the annual reports on the state of the environment in the Irkutsk Region) as well as forest and peat fires (Table 1), it was found that the contribution of forest and peat fires reached 23.0 - 9.6%, the average value for 8 years was 16.8%.

The qualitative composition of the combustion products is diverse; they contain toxic substances with a wide spectrum of action. Table 2 shows the average values of annual emissions of the priority most toxic atmospheric pollutants entering annually into the atmosphere of the Irkutsk Region during forest and peat fires.
Table 2. Indices of atmospheric pollution in the Irkutsk Region from stationary, officially recorded stationary sources and bulk emissions from forest and peat fires in the period from 2011 to 2018.

| Years | Index of atmospheric pollution from stationary sources | Index of atmospheric pollution from bulk emissions from forest and peat fires | Contribution of forest and peat fires from total stationary emissions, % |
|-------|--------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------|
| 2011  | 2.01                                                   | 0.36                                                                      | 18.0                                                                |
| 2012  | 1.38                                                   | 0.21                                                                      | 15.3                                                                |
| 2013  | 1.47                                                   | 0.19                                                                      | 12.9                                                                |
| 2014  | 9.95                                                   | 0.96                                                                      | 9.64                                                                |
| 2015  | 5.12                                                   | 1.18                                                                      | 23.0                                                                |
| 2016  | 9.93                                                   | 1.34                                                                      | 13.5                                                                |
| 2017  | 3.94                                                   | 0.89                                                                      | 22.5                                                                |
| 2018  | 3.98                                                   | 0.75                                                                      | 19.7                                                                |
| Average value |                                                           |                                                                           | 16.8                                                                |

Table 3. Average value of priority toxic substances released into the atmosphere from forest and peat fires in the Irkutsk Region for 2011-2018.

| Toxic substances | Emission mass, t·year⁻¹ | Toxic substances | Emission mass, t·year⁻¹ |
|------------------|--------------------------|------------------|--------------------------|
| Carbon dioxide   | 88026.11                 | Benzo(a)pyrene   | 8.49·10⁻¹                |
| Methane          | 63354.03                 | Toluene          | 6.79·10⁻¹                |
| Smoke (ultrafine particles) | 33560.25 | Acetaldehyde | 6.23·10⁻¹ |
| Acetic acid      | 28292.01                 | Sulfur oxide     | 3.62·10⁻¹                |
| Acetone          | 17428.14                 | Acrylonitrile    | 3.17·10⁻¹                |
| Soot             | 12319.93                 | Acetonitrile     | 3.17·10⁻¹                |
| Alkenes (C₅H₁₀)  | 10738.58                 | Hydrogen cyanide | 3.11·10⁻¹ |
| Methanol         | 8318.48                  | Isobutylene      | 2.72·10⁻¹                |
| Methyl chloride  | 1945.43                  | 2-Butene (butylene) | 2.72·10⁻¹ |
| Carbon oxide     | 1603.40                  | 1,3-Butadiene (divinyl) | 2.71·10⁻¹ |
| Acrolein         | 531.74                   | Naphthalene      | 2.71·10⁻¹                |
| Nitrogen oxide   | 356.99                   | Butane           | 2.04·10⁻¹                |
| Anthracene       | 87.41                    | Hydrogen sulfide | 1.16·10⁻¹ |
| Formaldehyde     | 59.73                    | Pentane and isopentanes | 1.58·10⁻¹ |
| Fluoratrene      | 17.63                    | Propane          | 1.13·10⁻¹                |
| Chrysene         | 17.63                    | Pentene and isopentenes | 1.13·10⁻¹ |
| Pyrene           | 17.63                    | Hexene and iso-hexenes | 1.13·10⁻¹ |
| Perylene         | 8.72                     | Pentene-1        | 9.05·10⁻²                |
| Propylene        | 7.69                     | Hexane           | 7.92·10⁻²                |
| Ammonia          | 3.96                     | Styrene          | 7.92·10⁻²                |
| Benzopheanthrene | 2.77                     | Ethylbenzene     | 7.92·10⁻²                |
| Ethylene         | 1.25                     | Alkanes (C₁₀H₂₂) | 1.13·10⁻² |
| Ozone            | 1.13                     | m, p - Xylene    | 3.39·10⁻³                |
| Benzene          | 1.08                     | Cresol           | 3.96·10⁻⁴                |

It was found that for the period 2011-2018 as a result of forest and peat fires on average up to 259.12 thousand tons of pollutants were released into the atmosphere annually.
4. Conclusion
Forest and peat fires make a significant contribution to atmospheric pollution in the Irkutsk Region. Atmospheric pollution is accompanied by other unfavorable environmental consequences. For instance, during peat fires, burning is slow due to the lack of oxygen and fire does not propagate as fast as on the surface, it forms burnt voids and there is a chance of falling into burnt peat.

Extremely high temperatures, burnout of oxygen, an increase in the concentration of combustion products in the air, smoke, destruction of vegetation - all this radically affects the stability of the natural biocenosis. Fires cause disruption of homeostasis, i.e. ecosystem constancy, due to the following factors:
1. a large number of animals and plants die in the fire, resulting in a further change in the species diversity of fauna and flora;
2. carbon dioxide, soot, nitrogen oxides and other combustion products release into the surface layer of the atmosphere, this changes the composition of the air;
3. disappearance of the forest intensifies the impact of winds on the soil, which can lead to its erosion and desertification of the land;
4. disappearance of trees and other vegetation after a fire changes the water regime of the soil;
5. burning out changes not only the water regime, but also the mineral composition of soils.

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