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Comparative Analysis of Environmental Risks of Wildfires in the Baikal Region

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Abstract

Introduction. The article is devoted to the problems of ecological consequences of forest fires in protected areas. It is proposed to assess atmospheric air pollution during forest fires and their impact on public health by the calculated method of specific emissions and hazard coefficients. The aim of the work is to perform a comparative analysis of environmental risks for the populations of three subjects of the Russian Federation in the Baikal region, and ranking of territories by the level of atmospheric air pollution during forest fires.

Materials and Methods. The initial data were statistical information on forest fires in the Irkutsk region, the Republic of Buryatia, the Trans-Baikal Territory in the period from 2013 to 2020, procedural documents of forest fires, including schemes and types of fires, areas and coordinates of fires, protocols of inspection of the fire site, acts of official investigation and other materials.

Results. The paper analyzes forest fires in the protected Baikal natural area of the Baikal region and their environmental consequences. The emphasis is placed on establishing the average annual characteristics of forest fires (number, area, economic damage, specific emissions of combustion product into the atmosphere, risks to public health). It is proved that bulk emissions from forest fires bring additional atmospheric pollution; it is 20 % of stationary sources of emissions. The Republic of Buryatia and the Irkutsk region contribute the most to the pollution of the atmosphere of the Baikal region.

Discussion and Conclusion. The methodology proposed by the authors for ranking territories by environmental risks can be used for predictive assessment of the consequences of fires for public health. The forecast results serve to support organizational and administrative measures, including decisions to attract additional forces and equipment, and to evacuate the population. According to the results of the forecast of the consequences of fires for the health of the population, a fire-fighting plan is being developed, which determines the methods and tactics of fire extinguishing, the distribution of forces and means, the decisive direction of actions, etc. According to the greatest contribution to the deterioration of living conditions and the risk of poisoning by combustion products, the studied territories are ranked in the following order: Irkutsk region – Republic of Buryatia – Trans-Baikal Territory.

Keywords: forest fires, environmental risk, pollution, forecasting, Baikal natural area, ranking.

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Introduction. Forest and landscape fires are among the most terrible and dangerous natural disasters that are widespread in the modern world and in the Russian Federation. Every year, people and animals die from uncontrolled fire, forests are destroyed, the oxygen and heat balance of the Earth is disrupted, the atmosphere, soil, water resources are polluted, there is toxic poisoning by combustion products and destabilization of the habitual lifestyle of the population, as well as air, river communications, rail and automobile traffic [1, 2]. Forest fires cause significant disturbances in aerodynamics and the state of the environment. The resulting convective flows spread gaseous combustion products and aerosols over considerable distances and cause significant harm to human health, the environment, and affect weather conditions [3, 4].

The constantly increasing number of fires and their size determine the relevance of the study of hazardous factors — the direct and indirect effects of the consequences of forest fires on ecosystems and human health [5, 6]. The forecast assessment of the impact of bulk emissions of combustion products of forest fires is currently not sufficiently developed. It is required to apply a systematic approach that allows taking into account the hazardous factors of fires, including the likelihood of risks to human health. Of undoubted scientific interest is the development of an integrated approach to assessing damage from forest fires, including a comparison of environmental losses at the level of specially protected areas.

The work objective is to perform a comparative analysis of environmental risks for the population of three subjects of the Russian Federation from the Baikal region, and to rank the territories by the level of atmospheric air pollution during forest fire.

Materials and Methods. The initial data were statistical information on forest fires in the Irkutsk region, the Republic of Buryatia and the Trans-Baikal Territory in the period from 2013 to 2020, procedural documents of forest fires, including schemes and types of fires, areas and coordinates of fires, protocols of inspection of the fire site, acts of official investigation and other materials.

Results. The paper analyzes forest fires in the specially protected Baikal natural territory of the Baikal region, their environmental consequences. The emphasis is placed on the establishment of the average annual characteristics of forest fires (number, area, economic damage, specific emissions of combustion products into the atmosphere, risks to public health) in the Baikal natural area, which has a special status.

As you know, the Baikal region covers the territory of the Baikal watershed and includes three subjects of the Russian Federation (Irkutsk Region, Trans-Baikal Territory and the Republic of Buryatia), as well as Mongolia. In accordance with Federal Law No. 94-FZ "On the Protection of Lake Baikal" of May 1, 1999, we distinguish the Baikal Natural Territory — the territory that includes Lake Baikal, the water protection zone adjacent to Lake Baikal, its catchment area within the territory of the Russian Federation, specially protected natural territories adjacent to Lake Baikal, as well as the territory adjacent to Lake Baikal with a width of up to 200 kilometers to the west and northwest of it. This territory is divided into three ecological zones — the central, buffer and ecological zones of atmospheric influence, for each of which the nature management regime is defined (Fig. 1).

Fig. 1. Map of the Baikal natural territory[1]

The Baikal natural area, as well as the Baikal region as a whole, is characterized by high forest cover. For example, the territory of the Irkutsk region has the highest forest cover (78 %) among the subjects of the Russian Federation. There are 21.6 hectares of forested area per capita in the Irkutsk region, which is almost 5 times more than the average in the Russian Federation and 84 times more than in Western Europe. 11.1 % of the all-Russian reserve of mature wood is concentrated on the territory of the region, and the share of the region for coniferous species is 13.4 %. The total area of land occupied by forests in the Republic of Buryatia, as of 01.01.2018, was 29,805.9 thousand hectares or 84.8 % of the total area of the republic. Almost the entire territory of Buryatia is covered with forests, most of which consists of coniferous trees (89.4 % of the total stock of forest plantations). The Trans-Baikal Territory ranks eighth in Russia in terms of the size of the felling-area resources available for forest use. Total forest reserves are estimated at 2.71 billion m^3 [7]. As of January 1, 2018, the total forest area of the Trans-Baikal Territory amounted to 34,065.8 thousand hectares. The probability of forest fires in the region is high.

The study is based on the analysis of statistical data of the Ministry of Forestry of the Irkutsk region, the Republican Forestry Agency of the Republic of Buryatia, the Chita Forest Protection Aviation Base, the Ministry of Emergency Situations for the period from 2013 to 2020 [8-10]. The authors carried out calculations using their own or involved methods [8-10]. At the first stage, the mass of substances released from forest fires was measured. The masses of substances were determined according to the method of the authors of the article, taking into account: the area of forest fires (ha), the combustion completeness coefficient, the emission coefficient, the stock of combustible material (kg/m^2). The assessment of possible adverse effects on public health — environmental risks — was assessed by hazard coefficients (HQ) and indices (HI) in accordance with the "Guidelines for assessing the risk to public health when exposed to chemicals that pollute the environment" [11].

It is established that annually on the territory of the Baikal region for the period from 2013 to 2020, an average of 3158 forest, 472 steppe and 30 peat fires occurred, as a result of which about 1,128.2 thousand hectares of natural territory were destroyed. Table 1 shows the authors' calculations based on the average values of the numbers of forest fires and their areas in the Baikal region based on information from sources [8–10].

[1] Baikal Natural Territory. Protected Baikal Region. Available from: https://baikal-1.ru/tourism/baikal-natural-territory (accessed 02.08.2022). (In Russ.).

Table 1

Average annual number and area of forest fires, taking into account their types in the Baikal region (2013–2020)

Research object	Ground fire				Crown fire				Peat fire	
	Running		Independent		Running		Independent		Independent	
	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares
Irkutsk region	383.3	57.7	896.7	134.8	8	15.6	18	29.3	9.4	7.9
Republic of Buryatia	236	79.2	639	184.8	6	6.4	15	11.9	13.0	6.9
Trans - Baikal Territory	141	36.2	685	92.5	8	15.1	23	26.9	8.9	7.5

During the studied period, there were mainly ground fires (98 % of the total number) in the Baikal natural territory, as a result of which 80.6 % of forest territories were destroyed.

Based on the information on the species composition of forests in the studied territories, the mass of burned forest-forming species was estimated. It was established that 972.7 thousand tons of pine, 825.1 thousand tons of larch and 664.0 thousand tons of cedar were destroyed per year (based on the information from sources [8–10]) (Table 2).

Table 2

Number of burnt forest-forming species in the Baikal region (average for 2013–2020)

Types of forest-forming species	Mass of burnt forest-forming species, t year^{-1}			
	Irkutsk Region	Republic of Buryatia	Trans-Baikal Territory	Baikal region
Pine tree	490 971.7	346 253.2	135 478.6	972 703.5
Fir	78 319.6	86 325.4	35 647.6	200 292.6
Silver fir	28 052.8	35 624.4	26 895.4	90 572.6
Larch	421 899.4	254 187.5	148 967.7	825 053.9
Cedar	165 965.4	325 684.5	142 369.4	634 019.3
Birch tree	229 178.0	189 635.0	125 461.0	544 274.0
Aspen	66 316.0	52 784.0	36 889.0	155 989.0

Table 3

Average annual economic damage from the loss of wood destroyed in the Baikal region during forest fires (authors' calculations according to [8–10])

Forest-forming species	Irkutsk Region		Republic of Buryatia		Trans-Baikal Territory		Baikal region
	Price, rub. per solid m^3	Damage, million rubles	Price, rub. per solid m^3	Damage, million rubles	Price, rub. per solid m^3	Damage, million rubles	Damage, million rubles
Pine tree	19.8	15.2	18.7	10.12	17.4	3.68	29
Fir	17.3	2.42	16.3	2.51	15.2	0.97	5.9
Silver fir	17.3	0.97	16.3	1.16	15.2	0.82	2.95
Larch	19.8	10.2	18.7	5.79	17.4	3.16	19.15
Cedar	19.8	5.86	18.7	10.87	17.4	4.42	21.15
Birch tree	6.6	1.68	6.2	1.31	5.7	0.79	3.78
Aspen	1.2	0.13	1.1	0.09	1.1	0.065	0.28

It is established that the annual economic damage from the destruction of forest-forming species, calculated as the product of wood destroyed in a fire by the cost of 1 solid m^3, is: in the Irkutsk region — 36.46 million rubles, in the Republic of Buryatia — 31.85 million rubles, in the Trans-Baikal Territory — 13.91 million rubles. The total economic damage in the Baikal region is about 82.22 million rubles (Table 3).

The mass of the i-th type of toxicant released into the atmosphere during wildfires was determined by formula:

$$G_i = K_{ai}^{\text{ЛГМ}} \cdot m^{\text{ЛГМ}} \cdot K_{ai}^{\text{Д}} \cdot m^{\text{Д}} \cdot K_{ai}^{\text{Т}} \cdot m^{\text{Т}}, \quad (1)$$

where G_i — mass of the i-th type of toxic substance released into the atmosphere; $K_{ai}^{\text{ЛГМ}}$—– emission coefficient of the i-th toxicant during the combustion of forest fuel, т/т; $m^{\text{ЛГМ}}$ — mass of burnt forest fuel, t; $K_{ai}^{\text{Д}}$ — emission coefficient of the i-th toxicant during the combustion of wood, t/t; $m^{\text{Д}}$ — mass of burnt wood (stand, crown), t; $K_{ai}^{\text{Т}}$ — emission coefficient of the i-th toxicant during the combustion of peat, peat soils, t/t; $m^{\text{Т}}$ — mass of burnt peat, peat soils, t.

The calculations have established that the average mass of eco-toxicants entering the atmosphere during fires in the Baikal region reaches 1,465 thousand tons, of which extremely dangerous substances — 0.2 thousand tons, highly dangerous — 4.34 thousand tons, moderately dangerous — 425.1 thousand tons, low-hazard — 517.28 thousand tons, other pollutants — 517.57 thousand tons (Table 4).

Table 4

Annual emission of combustion products by hazard classes as a result of wildfires and fires in 2013–2018 on the territory of the Baikal region

Research object	Atmospheric pollution by hazard classes of toxicants, thousand tons·year^{-1}				Other pollutants, thousand tons·year^{-1}
	Class I, extremely dangerous	Class II, highly dangerous	Class III, moderately dangerous	Class IV, low-risk	
Irkutsk region	0.08	1.97	197.95	240.70	240.04
Republic of Buryatia	0.06	1.38	143.10	171.78	165.20
Trans - Baikal Territory	0.06	0.99	84.07	104.80	112.33

The mass of uncontrolled emissions of toxic substances from forest fires depends on the season of the year (Table 5). The maximum emission of toxicants is observed in the spring (43.6%) and summer (48.4%) periods, in the autumn the emission of toxicants is insignificant (8%).

Table 5

Average annual mass of emissions of toxic combustion products into the atmosphere of the Baikal region, taking into account the time of year

Research object	Mass of emissions, thousand tons per year^{-1}			Total value, thousand tons/year
	Spring	Summer	Autumn	
Irkutsk region	297.3	329.9	54.5	681.7
Republic of Buryatia	209.9	233.1	38.5	481.5
Trans - Baikal Territory	131.9	146.3	24.1	302.3

The analysis of the population's treatment in hospitals in the region during the study period showed reliable signs of deterioration in the health of people in the smoke-filled zone. This fact is confirmed by the quantitative growth of the following indicators:

– respiratory diseases — 7.0 %;
– exacerbation of chronic bronchitis — 4.8 %;
– exacerbation of bronchial asthma — 5.9 %;
– exacerbation of cardiovascular diseases — 4.4 %;
– hospitalizations — 5.7 %;
– exacerbation of chronic diseases — 6.3 %.

The calculations have established that the average area of smoke in the Baikal region was 6.7 % (Table 6), and the specific load of the atmosphere with toxic combustion products in the Baikal region is 2.95 t/km^2·year^{-1} (Table 7). The average annual mass of emissions from wildfires is 37.84 % of the average annual mass of emissions from stationary sources of pollution.

Table 6

Average annual area of smoke on the territory of the Baikal region
as a result of wildfires in 2013–2020

Research object	Area of smoke, thousand km^2	As a percentage of the area of the region
Irkutsk region	57.6	7.5
Republic of Buryatia	27.5	7.8
Trans - Baikal Territory	20.7	4.8

Table 7

Average annual specific load on the atmosphere by toxic combustion products
in the Baikal region (2013–2018)

Research object	Area of the territory, km^2.	Amount of pollutants from stationary sources of pollution, thousand tons per year^{-1}	Specific load on the atmosphere from stationary sources of pollution, t/km^2·year^{-1}	Mass of gross emissions of toxic combustion products, t·year-^{1}	Specific load on the atmosphere with toxic combustion products, t/km2·year^{-1}
Irkutsk region	767 900	3 640.5	4.74	681 740	0.88
Republic of Buryatia	351 334	107.2	0.31	481 530	1.37
Trans - Baikal Territory	431 892	125.3	0.29	302 250	0.70
Baikal region	1 551 126	3873	5.34	1 465 520	2.95

The work assessed violations of living conditions and health risk ($R_{N\ забол.}$), according to formula:

$$R_{N\ забол.} = S_{зар.} \cdot 0.9 \cdot П_{нас.}; \quad (2)$$

where $S_{зар.}$ — the area of territory contamination, km^2; 0.9 — coefficient that takes into account the proximity of the fire to the populated area; $П_{нас.}$ — population density in the region, people/km^2.

The number of potential victims who could get sick from poisoning as a result of wildfires, based on the authors' calculations, is presented in Table 8.

Table 8

Assessment of violations of living conditions and the risk to human health
in the Baikal region (average for 2013–2018)

Research object	Population density, people/km^2	Area of pollution, km^2	Number of potential victims who could get sick from poisoning with toxic combustion products as a result of wildfires, people.
Irkutsk region	3.1	53 352	148 852.1
Republic of Buryatia	2.8	26 448	66 648.9
Trans - Baikal Territory	2.5	19 559	44 007.7
Baikal region	2.8	99 359	259 508.7

Discussion and Conclusion. The methodology proposed by the authors for ranking territories by environmental risks can be used for predictive assessment of the consequences of fires for public health. The results of the forecast serve to take organizational and administrative measures, including decisions on the involvement of additional forces and equipment, on the evacuation of the population. According to the results of the forecast of the consequences of fires for the health of the population, a fire extinguishing plan is being developed, which determines

the methods and tactics of fire elimination, the distribution of forces and means, the decisive direction of hostilities, etc. According to the greatest contribution to the deterioration of living conditions and the risk of poisoning by combustion products, the studied territories are ranked in the following order: Irkutsk region – Republic of Buryatia – Trans-Baikal Territory.

Thus, the authors have carried out a comparative analysis of the levels of atmospheric air pollution from forest fires in the Baikal region and found that:

– bulk emissions of toxic combustion products into the atmosphere make an additional contribution to the pollution of the atmosphere of the Baikal region. The annual emission of eco-toxicants into the atmosphere is about 20% of the mass of pollutants from stationary sources of pollution in the region;

– the Republic of Buryatia (the specific load on the atmosphere with toxic combustion products is 1.37 t/km^2·year^{-1}) and the Irkutsk region (the specific toxic load is 0.88 t/km^2·year^{-1}) make the greatest contribution to the pollution of the specially protected Baikal natural territory, the share of the Trans-Baikal Territory accounts for 0.70 t/km^2·year^{-1};

– according to the deterioration of living conditions and the risk of getting poisoning by combustion products, the studied territories are ranked in the following order: Irkutsk Region – Republic of Buryatia – Trans-Baikal Territory;

– the assessment of potential risk to public health by the hazard coefficient from exposure to combustion products showed that their values range from 0.9 to 47, the maximum values were recorded in the Irkutsk region;

– based on the above studies and the assessment of the contribution of forest fires to the deterioration of the ecological situation, a comparison of the subjects of the Russian Federation of the Baikal region by gross emissions of toxic combustion products was carried out. It is established that the Irkutsk region is the most environmentally risky territory.

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S. S. Timofeeva — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions. V. V. Garmyshev — analysis of the research results, revision of the text, correction of the conclusions. A. Yu. Astrakhantseva — collection and analysis of information, calculations.

Conflict of interest statement

The authors do not have any conflict of interest.

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