Landscape fire in East Siberia: medical, ecological and economic aspects

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Abstract. More than 40% of the forests in Siberia region are known to have a fire danger of high classes and high burning degrees. This paper describes air pollutants emission (PM10, nitrogen oxides, sulfur dioxide and others) in East Siberian region during a 10-year period in the forests fires focus. A total of 500 to 2000 fires occurred in Irkutsk oblast during the last ten years. At an average annual forest fires cover an area of 1 109 hectares on the model territory (Bratsk city). The plane pollutant emission source with a high productivity is formed on the significant forest fire area occurred in a relatively short-term time periods. The increase in hazard ratios was registered for the ingredients of emission-specific industrial enterprises and capable of accumulating in vegetation: carbon disulphide 1.9 times, fluorine-containing substances 1.8 times during the fire. The economic loss of energy resources resulting from reduced production of firewood was estimated at $ 56.6 million in Irkutsk oblast. The potential risk of negative effects for the respiratory system and cardiovascular system stipulated for the acute inhalation exposure was found to increase on the days, of the fires, as evidenced by the growth of the daily mortality and morbidity rates among the population.

1. Introduction
There are 150 thousand forest fires on average every year in Russia, the US, Canada, and Brazil, and about 1.5 million hectares of land are burned on average in each case. Other countries also experience an annual average of 150 thousand fires, though the average area that catches fire is not large, except for Argentina. Ignition conditions, physicochemical characteristics of flora (tree species, age, forest types, etc.), the weather, climate, season, time of day, and other factors influence a fire’s parameters. All these factors can cause a fire to spread quickly, which means that their characteristics and intensity influence the natural ecosystem [2]. Radiation from a forest fire as well as the vast amounts of harmful substances and other elements emitted influence the environment globally, going beyond the region [3, 5, 7, 13]. For example, it is clear that the fire risk is higher when the air temperature is high and the air is dry (when the humidity is relatively low). Some have positive view that a fire modifies natural components of a forest ecosystem, but firstly we would like to have a look at key negative factors of a forest fire, i.e., a forest fire is a strong factor in air pollution; a forest fire generates noxious substances (sulphur dioxide, carbon monoxide, dust, etc.) and destroys the forest ecosystem. It triggers changes in the local ecology and climate, as well as the oxygen balance in the atmosphere; a forest fire destroys the surface of the land more widely than erosion by a rainstorm. It leads to the risk of the ground sinking and collapsing. It changes freshwater flow of rivers, swamps, and lakes, and triggers thawing in permafrost areas.
The many substances that are generated by a forest fire are harmful to people and animals, as well as to vegetation. A large forest fire is threatening. It frequently destroys houses, industrial complexes, and entire villages. Eighty percent of fires that occur in all countries is caused by men, and another 5-7% is caused by nature. The cause of the other fires has not been identified. In Russia since the 1990s every 2-4 years forest and peat fires had catastrophic scales, threatening environmental population of certain subjects and regions of the country [2, 6]. The consequences of the natural fires may be divided into ecological and socio-economic ones. The structure destruction and the function disorders of the natural ecosystems, the alteration of the biogeochemical cycles, the soil humification processes on the territories exposed to pyrogenic factors are known to concern with a number of serious ecological consequences [4, 5, 11]. The potential impact of smoke from prescribed burning on occupational and community smoke exposures and related health effects are of growing concern. A number of studies have also demonstrated or assumed adverse health effects in individuals from communities exposed to smoke from wildland fires [1, 8]. People and material losses were revealed to be more significant social-economic consequences of natural fires, prevalence of which continues to be high in many planet regions in the recent years [13]. So, as evidenced by the preliminary assessment, about a half of the summary economic loss because of the natural fires in 2010 in the European part of Russia has been stipulated for health disorders (people’s death, higher applying for medical care) [9].

2. Methods
The Siberia region belongs to a number of the territories with a high degree of woodiness where the forest proportion, mainly light-coniferous ones, is known to amount more than 60% of a common area of its territory. More than 40% of the forests in this region are known to have the fire danger of high classes and high burning degrees. In Russia, areas with the highest fire risks are Irkutsk Oblast, Zabaikal Krai, and Khabarovsk Krai. The more fire dangerous period in this region is known to be correlated with the spring and autumn months when the high air dryness with the prevalence of windy weather may lead to strong drying the soil surface up and form favorable conditions for occurrence and development of forest fires. This work is aimed to calculate the concentrations of CO, NOx, total PM (TPM) in the distance from the fire focus to the points according to the observation posts for concentration of air pollutants on the residential part on the example of the forests fires in the vicinity of Bratsk (Irkutsk oblast). To characterize the forests fires, the data of the territorial Department of State Forest Service in Bratsk of Irkutsk oblast have been used. The data of the observation posts have been presented by the Centre of Hydrometeorology and environmental monitoring. The values of multiple monitor’s data for TPM and gaseous pollutants (SO2, NO2, NO, H2S, formaldehyde and CO) are included. Weather variables from Bratsk were also distributed in this data set, including daily mean temperature, relative humidity, precipitation, pressure, resultant wind speed and direction. To assess the pollutant volumes, the calculation algorithm of summary emissions of pollutants to the atmosphere for the low-based forest fires, as well as the relative values of the emission coefficients have been used:

\[ M_{ai} = S_j \cdot K_j \cdot K_{ai} \cdot m_{30j} \]  \hspace{1cm} (1)

Here \( S_j \) is the forest territory area being exposed to fires, \( m^2 \); \( K_j \) is the burning fullness coefficient (0.5); \( K_{ai} \) is the alpha-pollutant emission coefficient, kg/kg; \( m_{30j} \) is the combustible forest material emergence, kg/m³.

The theoretically-probability mean maximal value \( C_m \) (mg/m³) of the pollutant concentration in the point \( x \) during the time moment \( t \) was calculated using the equation:

\[ C_m = K \frac{P}{\pi \sigma_x \sigma_f U} \exp \left[ -\frac{1}{2} \left( \frac{x}{\sigma_f} \right)^2 \right] \]  \hspace{1cm} (2)

Here \( P(x',t') \) is the source productivity in the point \( x' \) during the moment \( t' \); \( \sigma_x(f) \) are the standard deviations \( (i = 1, 2, 3; f = t' - t) \); \( K \) is the coefficient taking into account emission source type; \( x_j \) is the height of pollutant emission source.
We calculated Hazard coefficient ($HQ$) and Hazard Index ($HI$) by formulae 3 and 4 respectively:

$$HQ = \frac{C_m}{Rfc}$$  (3)

$$HI = \sum HQ$$  (4)

Here $Rfc$ is the reference concentration ($\text{mg/m}^3$) recommended by World Health Organization (WHO) for inhalation exposure.

3. Results and discussion

Analysis of the climatic factors and records on fires in Siberia indicates that the forest fires in this area have cycles of 3-4, 11, and 61-62 years, and shows the humidity distribution in Central and South Siberia from May to June and in North Siberia from July to August. The fire cycle of one of the fire sites was shortened to 11 years and 7 months due to human activity. Each fire in spring generally destroys 45-80 hectares, indicating a level of force that is in the low-mid to high range.

Fires that occur in industrial areas are especially dangerous. Long-term release of industrial wastes exacerbates the destruction of the forest ecosystem, cause an imbalance in air components, and cause harmful substances to accumulate in plant fiber. The amount of smoke generated in the event of a forest fire in an industrial area is 34% in the case of poplar, 51.1% in the case of birch, 37.7% in the case of aspen, and 69.1% in the case of the bark of broadleaf trees [12]. Key air pollutants that are generated in the event of a large forest fire in an industrial area include CO, CO$_2$, NO$_x$, SO$_2$, H$_2$S, C, HCN, SiO$_2$, HCHO, organic acid, and benzopyrene. According to a 2015 assessment, only in Irkutsk, the amount of poisonous substances discharged into the air as trees burned down during the fire risk period reached 75 tons.

From among 52 indexes, statistics, such as the number of forest fires, land area burned by fires, number of residents in affected areas, components of the forests that burned (grass, boughs, etc.), and the number of trees that burned down, were used to identify factors that influence the components of poisonous substances that are substantially discharged into the air in the event of a forest fire. Based on such statistics, the research was carried out to discern and forecast the number of fires and risk areas from the discharge of poisonous substances.

Research models were devised in Bratsk City, Irkutsk oblast. A total of 500 to 2000 fires were occurred in Irkutsk oblast in the last ten years. Over a ten-year period in the Irkutsk region, forest fires damaged an average of 61,623 hectares (table1).

Table 1. Average characteristics of the forest fires in the period from 2003 to 2013 in Irkutsk Oblast and Bratsk District.

| Territory          | Area of forest fires, ha | Mass of pollutants, ton | Average damage from forest fires, thousand rubles |
|--------------------|--------------------------|-------------------------|-----------------------------------------------|
|                    | M±m                      | Min         | Max          | M±m | Min | Max |                               |
| Bratsky District   | 1,109±611                | 40              | 5,586        | 1,532±843 | 55 | 7,773 | 68,466                        |
| Irkutsk Oblast     | 61,623±18,312            | 7,214        | 193,685      | 85,088±25,286 | 9,961 | 267,439 | 943,653                        |

In Bratsk district at an average annual forest fires cover an area of 1,109 hectares. On average, during the period under review, 85,088 tons of pollutants were allocated by forest fires in Irkutsk region, and 1,532 tons were allocated in Bratsk district. The economic loss of energy resources resulting from reduced production of firewood for fuel was estimated at 326,000 dollars, and the loss of lumber for industrial use was estimated at 285,000 dollars. The incineration of trees reduced the
stores of available lumber, productivity of the forest stemming from the nutritive conditions of the ecosystem’s energy and material flow. This is regarded as a loss to the forest ecosystem caused by fire.

Bratsk City has a population of about 300 thousand people. On the territory of Bratsk district, in the period of 17 September and 6 October 2011, forest fires took place on a total area of 6 928 hectares. The period of high altitude of forest territories lasted 20 days and the areas of forest fires were from 10 hectares to thousands of hectares.

As a result of burning forest vegetation in the designated territory, the following pollutants were released into the air: carbon monoxide – 9.1, total particulate matter – 4.5, PM2.5 – 2.2, carbon black – 0.7, acetaldehyde – 0.6, sulfur dioxide – 0.0000648 tons a day. The summary pollutant emission mass was found to be increased according to the fire area. The higher emission masses, independent on the fire area, were characteristic for CO and TPM formed in the smoldering of forest combustible materials stored in the landfills of woodworking enterprises. Traces of smoke and an increase in air pollution were detected at the site of a major forest fire close by a residential area. During the first week after the fire, the hygiene index increased more than four times due to pollutants, carbon monoxide more than five times, nitrogen dioxide at least six times, phenol at least 4.2 times, formaldehyde at least two times, and sulphur dioxide at least 2.5 times.

High productivity of a forest fire over a large area has led to large concentrations of pollutants estimated. The results of calculations are compatible with the CO and TPM at the observation posts well. The real data of the observation post testify the increase in the contents of CO 4 times (1.0 mg/m3), the TPM 1.6 times (0.2 mg/m3). In the period of massive landscape fires, the ranking of the danger of air pollutants for population of Bratsk can be presented in the form of the following series: PM10 and PM2.5, carbon black, carbon monoxide, nitrogen dioxide, hydrogen sulphide, acrolein, and formaldehyde. Air pollutants have the greatest danger for the respiratory system and cardiovascular system. The increase in hazard ratios was registered for the ingredients of emission-specific industrial enterprises and capable of accumulating in vegetation, namely carbon disulphide 1.9 times, fluorine-containing substances 1.8 times during the fire.

Taking into account the admixture activity trends emitted to the atmospheric air the priority classes of diseases have been determined in the formation of which the air quality may play a significant role (respiratory diseases and circulation organ diseases). Formaldehyde, nitrogen dioxide, TPM, carbonic oxide, sulfur dioxide is known to belong to the ingredients giving the danger level for the classes indicated. The hazard index (HI) stipulated for the short-term exposure was found to be on the average 3.91. The maximal HI = 19.1 was observed to be in September on the day with dangerous wind rate. The analysis of the climatic parameters testified that the higher pollution levels were just observed to be in those days. The prevalence of the daily death cases based on these causes is considered. It was found that, on the average, 0.22 death cases were registered due to the diseases of the cardiovascular system per day and 0.032 were because of the pathology of the respiratory organs. On the day with the maximal HI level 3.0 death cases have been registered due to the cardiovascular diseases (CVD), 1.0 were due to the respiratory organ diseases (ROD). The daily applying for the urgent medical care, based on the causes of studying, did not practically differ and it was 10.5 (CVD) and 10.2 (ROD) of cases in average. During the first two or three days, there was thick smoke, and 1.3% of the city’s population went to the hospital. The incidence of deaths due to circulatory system diseases increased 2.5 times. An analysis of the pollution led to statistical materials (r=0.46, p=0.002) indicating a more than five-fold increase in the level of danger caused by such short-term impact on health such as deaths from breathing and circulatory system diseases, as well as the use of ambulances. The total number of patients hospitalized increased by 10%. The corresponding figure for children was 17%.

The information assessment of the environmental factors for forming the population mortality rate has been performed using the method by Shepard. The following more significant factors influencing on the population health disorders during the fire periods have been revealed, i.e. the wind rate, the TPM contents, air temperature, the contents of soot and formaldehyde. A number of the significant predictors on the days without the fire may have another order (table 2).
Table 2. Predictor significance for forming the population mortality among the population of Bratsk.

| Predictor            | Forest fire days | Days without fires |
|----------------------|------------------|--------------------|
| $T^\circ C$          | 0.0019           | 0.0019             |
| TPM                  | 0.0020           | 0.0014             |
| Wind rate            | 0.0020           | 0.0012             |
| Formaldehyde         | 0.0007           | 0.0005             |
| Black carbon         | 0.0011           | 0.0003             |
| NO$_2$               | 0.0003           | 0.0001             |
| CO                   | 0.0005           | 0.0001             |
| SO$_2$               | 9.5711           | 6.0679             |

In addition, the most important factors of harm to the health of residents in the event of a fire were identified. Harm to the health of residents triggers a substantial economic loss of 8.0 million dollars. A rise in deaths also leads to great economic losses. Economic losses stemming from hospital treatment for less than 1% of residents total 120 thousand dollars in seven days, accounting for 0.01% of annual GRDP [7]. The total economic losses calculated based on official materials in Bratsk were 72.1 million dollars. The amount stemming from harm to health (deaths, hospitalization) is presumed to total 3.2 million dollars, costs incurred from extinguishing fires are 0.45 million dollars, and losses to forest resources are 68.5 million dollars.

The forest fires in the neighborhood of the populated areas may contribute to the air pollution and they are known to be one of the causes of their forming smoke-screen. For example, the heaviest smoking has occurred in Moscow due to the wild fires in the central regions of Russia in 2010 that is why the maximal concentration of CO, specific hydrocarbons and the total PM was significantly higher than the allowed level, already in the first decade of August 2010 [9, 10]. The suspended particles with size of 10 micrometers (PM10) or less (0.0004 inches or one-seventh the width of a human hair were found to be more dangerous for human health). Major concerns for human health from exposure to PM10 include the following: effects on breathing and respiratory systems, damage to lung tissue, cancer and premature death [9].

4. Conclusion

Forest fires served to adjust the forest ecosystem during the last century, but now they are regarded as disasters from the perspective of the economy, society, and ecology. There is a periodical occurrence of major fires that require mobilization of tremendous resources and methods to combat and extinguish them. That is why forecasting such disaster is essential. Effective forecasting would minimize losses by improving the ability to respond to such disasters and establishing better ways to respond to them.

References

[1] Analitis A, Georgiadis I and Katsouyanni K 2012 Forest fires are associated with elevated mortality in a dense urban setting Occup Environ Med 69 158–62
[2] Bacciu V, Spano D and Salis M 2015 Emissions from Forest Fires: Methods of Estimation and National Results The Greenhouse Gas Balance of Italy 87-102
[3] Chertov O G, Komarov A S, Gryazkin A V, Smirnov A P and Bhatti D S 2013 Simulation modeling of the impact of forest fire on the carbon pool in coniferous forests of European Russia and Central Canada Contemporary Problems of Ecology 6(7) 727-33
[4] Coluzzi R, Masini N, Lanorte A and Lasoponara R 2010 On the Estimation of Fire Severity Using Satellite ASTER Data and Spatial Autocorrelation Statistics Lecture Notes in Computer Science 6016 361-73
[5] Ganteaume A, Camia A, Jappiot M, San-Miguel-Ayanz J and Lampin C A 2013 Review of the main driving factors of forest fire ignition over Europe *Envir Management* 51(3) 651-62.

[6] Isaeva L K, Solovyov S V, Sulimenko V A and Shilin S A 2010 Environmental impacts of forest and peat fires in the Moscow region in 2002-2009 years *Fires and emergencies* 3(10) 85-91

[7] Mavsar R, Varela E, Corona P, Barbati A and Marsh G 2012 Economic, legal and social aspects of post-fire management *Post-Fire Management and Restoration of Southern European Forests Managing Forest Ecosystems* 24 45-78

[8] Naehler L, Brauer M, Lipsett M, Simpson C, Koenig J Q, Zelikoff J and Smith K R 2007 Woodsmoke health effects: a review *Inhal Toxicol* 19 67-106

[9] Shaposhnikov D, Revich B, Bellander T C, Bedada G B, Bottai M, Kharkova T, Kvasha E, Lezina E, Lind T, Semutnikova E and Pershagen G 2014 heat wave and wildfire air pollution related mortality in the summer of 2010 in Moscow *Epidemiol* 25(3) 359–64

[10] San-Miguel-Ayanz J, Pereira J M C, Boca R, Strobl P, Kucera J and Pekkarinen A 2009 Forest Fires in the European Mediterranean Region: Mapping and Analysis of Burned Areas, Earth Observation of Wildland Fires in Mediterranean Ecosystems Ed. E. Chuvieco (Berlin Heidelberg: Springer-Verlag) pp 189-203

[11] Sherstyukov B G and Sherstyukov A B 2014 Assessment of increase in forest fire risk in Russia till the late 21st century based on scenario experiments with fifth-generation climate models *Rus Meteorology and Hydrology* 39(5) 292-301

[12] Timofeeva S S, Garmyshev V V and Zyryanov V S 2012 Smoke situation when burning forest combustible materials in urban and suburban areas of cities *Bul of the Irkutsk State Technical University* 3(62) 50-55

[13] Vadrevu K P, Eaturu A and Badarinath K V S 2010 Fire risk evaluation using multicriteria analysis – a case study *Environ Monitoring and Assessment* 166 223-39