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Research article

CLIMATE CHANGE AND FOREST FIRES AS HEALTH RISK FACTORS (ANALYTICAL REVIEW)

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Climate change in Russia contributes to an increase in the number of forest fires, especially in Siberia and the Far East, leading to the rise in the forest fire danger index. Increased air pollution, which is typical for a number of cities in these regions, is the reason for changes in population health due to the influx of significant volumes of smoke gases from forest fires into populated areas. Smoke from forest fires consists of aerosols and gases and contains more than 40 pollutants. During fires, frequency of calls for emergency medical care for children tends to increase due to exacerbation of upper respiratory tract diseases, including laryngitis, pharyngitis and acute respiratory infections, as well as attacks of bronchial asthma, and longer exacerbation periods of this disease. Such respiratory dysfunctions appear a few days after fires, which should be taken into account when organizing health monitoring in such situations. Among adult population, an increase in the number of deaths from cardiovascular and respiratory diseases has been proven during forest fires, and there tends to be an increase in the number of requests for medical care for COPD, bronchial asthma, myocardial infarction, coronary heart disease and other diseases. Fires in forest highlands in the Khabarovsk Krai result in deteriorating health of patients with neurological diseases.

The generalization of the results obtained by domestic and foreign studies on this issue confirms the need to improve the air pollution monitoring system during forest fires with the determination of PM for timely preventive measures by health systems, Rospotrebnadzor, FMBA and other agencies. It also seems necessary to develop modeling of pollutant spread in ambient air in settlements exposed to them, with assessments of population health risks and development of preventive measures. Given the relevance of these studies, it is advisable to hold seminars with BRICS countries within the framework of international cooperation.

Keywords: *climate change, forest fires, population mortality and incidence, diseases of the upper airways, bronchial asthma, air quality monitoring, risk factor.*

The number of forest fires is growing constantly all over the world due to variable reasons including draughts as a consequence of climate change, dried grass burning in agricultural activities, human factor etc. Approximately 54 % of the forests on the planet are located in five countries: Russia, Brazil, Canada, the USA, and China. Over the last 20 years, the number of severe forest fires has doubled across the globe. Up to 700 forest fires happen annually in European countries only, French Corsica, Greece and Italy being the leaders in this respect. In the USA, most fires occur in western states and they tend to be very strong and very long. Climate change, global warming included, long draughts and dry thunderstorms have had considerable influence on the growth in the number of forest fires due to an increasing number of heat waves and soil degradation. This has become a new and a rather serious global challenge [1–3]. It is urgent in Russia as well since forest fires are becoming more and more frequent in the country. In the period up to 2020,

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their number grew by 10 % annually against 2016 [4]. According to various predictions, their duration can grew by 20–29 days and even more in the whole European part of Russia by 2099 [5]. In 2022–2023, a wave of fires occurred in 70 regions in the country and 4 million hectares were affected by them. The greatest forest fires were observed in the Amur, Sverdlovsk, Omsk, and Chelyabinsk regions, Zabaikalskii and Khabarovsk Krai, Jewish Autonomous Area; they also occurred in Yakutia, Magadan, Irkutsk, Tyumen, and Novosibirsk regions[1]. The Federal Forestry Agency reported that no settlement was affected by fires in 2023; still, this assessment does not consider effects of smoke gases on ambient air quality and population health in urban and rural settlements.

Global warming has become one of the basic reasons for forest fires in Siberia where temperatures were constantly above their normal climatic range. Thus, the highest air temperature above 38 °C was registered in Verkhoyansk and this has become a new temperature record to the north of the Northern Polar circle. High temperatures make the soil surface drier and more combustible, which makes for early occurrence of seasonal forest fires and a growth in their overall area [6]. In 2019, abnormal climatic conditions were observed in Siberia due to climate change. Smoke from fires in Krasnoyarsk Krai affected territories with approximately 10 million people living there in Omsk, Tyumen, Sverdlovsk, and Chelyabinsk regions and Perm Krai [7]. In summer of 2021, smokes from the record number of fires in Siberia covered more than 3000 km distance and reached the Northern Pole. The number of lightning strikes tripled to the north of 65° northern latitude, which created even greater risks of forest and tundra fires [6].

Yakutia holds the first place among RF regions per the number of forest fires almost every year. This is the largest territory in the country where the fire area reaches 8–10 million hectares over the fire season [8–10]. Fire recurrence in Siberian forests depends on their composition. For example, more fires tend to occur in shallow light coniferous forests located in the center of Eastern Siberia in comparison with its western part. More forest fires typically occur in the southern part of the mid Siberia and their frequency is growing persistently[2].

Forecast scenarios of fire frequency in Russia have been developed for more than 10 years by institutions of the Russian Academy of Sciences and Rosgidromet; this frequency is expected to grow in the Asian part of the country [11–15]. The strongest and longest forest fires should be expected in the south of this territory where temperature rise is accompanied with lower precipitations and higher values of the fire danger index. This zone includes southern areas of Kemerovo, Omsk and Irkutsk regions, Zabaikalskii Krai and some other territories. Climatologists believe the fire danger index might grow 2.5 times as high against its level in the end of the 20th century [14]. However, the number of forest fires has been growing in the European part of Russia as well. For example, in the Volga Federal District, their frequency was the highest in Nizhnii Novgorod and Samara regions in 1992–2020 [16].

The composition of forest fire smoke. Forest fires create smoke that consists of an aerosol mixture with particles of various diameters and volatile compounds. Their physical and chemical properties change as a distance from a fire seat grows and also due to dispersion in ambient air. Smoke gases created by forest fires tend to contain more than

[1] Federal'noe agentstvo lesnogo khozyaistva [The Federal Forestry Agency]: official web-site. Available at: https://rosleshoz.gov.ru/ (July 04, 2024) (in Russian).

[2] Valendik E.N., Arbatskaya M.K., Vaganov E.A., Volosatova E.N., Ivanova G.A., Levkina O.I., Ovchinnikov D.V., Shashkin E.A. Prognozirovanie chastoty lesnykh pozharov v Sibiri v svyazi s global'nymi izmeneniyami klimata [Predicting frequency of forest fires in Siberia due to global climate change]: the Report for the Russian Foundation for Basic Research grant, 1997 (in Russian).

40 chemicals including carbon oxides (CO and CO_2), methane, methanol, methyl chloride, solid aerosols (including black carbon), acetone, acrolein, and others. Acetone contents increase in smoke gases in case of peat burning [10]. There are also some data on more complex composition of smoke gases created by forest fires. If landfills with solid household wastes, some equipment or buildings with polymers in their structure are brunt in a forest fire, this may result in occurrence of free radicals, hydrogen cyanide or other hazardous chemicals in smoke gases [17].

Smoke near a fire seat contains large quantities of particulate matter (PM) sized 2.5 μm and more but as it spreads further, the number of even smaller particles grows in it. Russian toxicologists have investigated and reported toxic effects of some specific ambient air pollutants including carbon monoxide, sulfur and nitrogen oxides, aldehydes, PAHs, phenol, and heavy metals in hundreds of publications. Over the last 15 years, toxic effects produced by small-sized particulate matter have been constantly investigated by experts; new data have been reported and several reviews on the issue have been published in Russian [18]. Fine-dispersed particles with their diameter not exceeding 0.1 μm are considered gases and their carcinogenic effects are being investigated quite intensively at the moment.

Fires and ambient air pollution. The results obtained by estimating ambient air pollution with PM and other chemicals during forest fires and following days have been published only for several Russian cities. During the abnormally hot summer of 2010, forest fires occurred in the eastern part of Moscow region and fire smoke spread for more than 100 km reaching western areas of the region. The Poisson regression model for daily mortality was employed to estimate effects of exposure to PM_{10} on population mortality in Moscow during that period. Daily all-cause natural mortality was taken as the dependent variable, which conformed to the Gaussian distribution. Average daily PM_{10} levels within 53 μg/m^3 were established to have no effect on the average long-term rates of all-cause natural mortality; a gradual rise in mortality was observed under levels within 53–96 μg/m ^{3}and the peak in it was reached under levels equal to 138 μg/m ^{3} [19]. At the same time, MPLs were violated as regards such hazardous chemicals as nitrogen oxides, benzo(a)pyrene, and formaldehyde [20].

In 2010, forest fires were the reason for ambient air pollution in woody areas in many regions of the RF European part, which led to premature mortality among population. For example, mortality due to all natural causes, external ones excluded, grew by more than 1.5 times in Voronezh region (68.7 %) [21]. There was solid evidence of an authentic correlation between air temperature and carbon oxide levels in ambient air and hospital admissions due to all diseases; moderate and strong correlations were established between levels of particulate matter and the total mortality rates [22–24]. Ambient air was found to be polluted with carbon oxide, nitrogen dioxide, particulate matter, formaldehyde, and hydrocarbons during forest fires in Voronezh, Samara, Saratov and other regions. Thus, in 2018, a correlation was established in Saratov region between the fire area and dynamics of single maximum levels of nitrogen dioxide ($r = 0.47$, $p < 0.05$), particulate matter ($r = 0.57$, $p < 0.05$) and hydrocarbons ($r = 0.62$, $p < 0.05$). Probabilistic health risk due to short-term inhalation exposure was above safe HQ levels per nitrogen oxide, particulate matter, and formaldehyde [25]. The results of this study confirmed those obtained by earlier works with their focus on assessing children's health during forest fires, which established higher frequency of upper respiratory airways diseases and their longer exacerbation periods [26].

People who live in cities in Siberia and the Far East with elevated ambient air pollution levels can be considered among population groups that are the most susceptible to effects produced by forest fires. These cities are included into the Clean Air Federal project: Bratsk, Krasnoyarsk, Chita, Irkutsk and some others. In Krasnoyarsk, concentrations of ambient fine-dispersed PM_{10} were above safe

levels established in Russia (60 μg/m^3) and those recommended by the WHO (50 μg/m^3)[3]. The similar 2018 report did not contain any data on PM_{10} levels but still mentioned that levels of all particulate matter grew by 1.7–2.3 times. This means that levels of fine-dispersed particles, which pose the greatest health hazard, also grew[4]; exposure to such particles may result in a growth in the total mortality rate for urban population by 9.3–21.9 % [27].

High levels of ambient PM during forest fires are typical for foreign countries as well. PM_{10} and $PM_{2.5}$ concentrations were increased during the occurrence of large fires and megafires in Portugal, with daily concentrations exceeding the European/national guidelines in 7–14 and 1–12 days of 2017 (up to 704 μg/m^3 for PM_{10} and 46 μg/m^3 for $PM_{2.5}$), respectively. PM_{10} concentrations were correlated with total burned area ($0.500 < r < 0.949$; $p > 0.05$) and with monthly total burned area / square distance ($0.500 < r < 0.667$; $p > 0.05$) [28]. The largest forest fires in the USA usually occur in California. More than 9600 forest fires were detected in this state solely in 2020, which resulted in economic losses billions of dollars' worth. It is these fires that create up to 32–44 % of all $PM_{2.5}$ emissions in the USA. $PM_{2.5,}$ as a component in a complex mixture of solid particles and gaseous pollutants in smoke, create the most serious challenge for public healthcare due to their known health risks, high levels, and spacious dispersion during forest fires. Elevated $PM_{2.5}$ levels are hazardous both for respiratory organs and cardiovascular system.

Effects produced on human health by ambient air pollution due to forest and peat combustion gases. According to PubMed data, more than 70 articles have been published on the issue, which is hundreds and thousands of times less than on any other health risk factor. Such investigations are predominantly accomplished in Brazil with its gigantic forest fire areas in the Amazonian region; also, we should mention the USA, Canada, Greece, and some other European and South-Asian countries.

Population mortality. Russian investigations on the issue have been conducted only in several regions including Moscow, Voronezh and Irkutsk region, Chita, and Khabarovsk Krai. During the hot summer of 2010, combined exposure to abnormally high temperatures and elevated ambient air pollution due to forest and peat fires resulted in an authentic increase in mortality by 11,000 deaths in Moscow. A mathematical model, which was developed in this study, established this growing mortality to be authentically dependent on combined exposure to elevated levels of ambient PM_{10} and ozone as well as abnormally high air temperature and duration of a heat wave [29]. A highly adverse situation is observed in Chita where emissions can hardly disperse in ambient air in residential areas during forest fires due to the city being located in a hollow between mountain chains. Levels of practically all analyzed chemicals were higher than seasonal background values during forest fires and levels of particulate matter, CO, NO_2, and black carbon were several times higher than single and average daily MPLs. Calculated concentrations were confirmed by field measurements: levels of $PM_{2.5}$, total solid particles, carbon oxide, and black carbon were above their MPLs within a 5–10 km radius; acetaldehyde, up to 20 km radius. Average acute hazard quotients (HQac) were above 1 meaning elevated levels of health risk, which was also confirmed by higher calls for emergency due to diseases of the respiratory and circulatory system among children younger than 17 years and adults older than 65 years during forest fires. The

[3] O sostoyanii i okhrane okruzhayushchei sredy v Krasnoyarskom krae [On the quality and protection of the environment in Krasnoyarsk Krai]: 2017 State Report. *Krasnoyarsk Regional Ministry of Ecology and Rational Use of Natural Resources.* Available at: http://www.mpr.krskstate.ru/envir/page5849/0/id/32983 (May 17, 2024) (in Russian).

[4] O sostoyanii i okhrane okruzhayushchei sredy v Krasnoyarskom krae [On the quality and protection of the environment in Krasnoyarsk Krai]: 2018 State Report. *Krasnoyarsk Regional Ministry of Ecology and Rational Use of Natural Resources.* Available at: http://www.mpr.krskstate.ru/envir/page5849/0/id/39742 (May 17, 2024) (in Russian).

number of such emergency calls grew 1.5–4 times as high[5] [30, 31]. A database on emergency calls by population, which was created by the authors, was granted a certificate by Rospatent and this is a significant example of preparing initial medical data on effects produced on human health exactly by smoke gases created by forest fires. Such information typically contains data on forest fires, levels of pollutants in ambient air in Chita and numbers of emergency calls. Therefore, it can be used later within social-hygienic monitoring activities to objectively assess consequences of these natural disasters[6].

Another method for assessing health risks upon chemical exposures was approved by Rospotrebnadzor. It was employed by the same group of authors to estimate consequences of forest fires in Bratsk, Irkutsk region [32]. Masses of chemical emissions were determined according to The Method for Determining and Calculating Pollutant Emissions from Forest Fires; levels of pollutants in ambient air were calculated for the analyzed city; health risks were assessed and emergency calls were analyzed. Up to 82 % of the Irkutsk region area is covered with forests and the number of hospital visits usually grows during forest fires primarily due to respiratory diseases by 6.5 %, exacerbation of chronic bronchitis by 4.2 % and bronchial asthma by 5.2 % [10].

Khabarovsk region holds the first place among RF regions per areas of highland forests. Levels of particulate matter, nitrogen dioxide, phenol and formaldehyde were considerably higher than MPLs during forest fires in this region [33]. Effects produced by forest fires on population mortality were estimated in various districts of the region in 1997–2001 by comparing its rates depending on fire frequency. Unfortunately, it is rather difficult to estimate quantitative relationships between levels of pollutants and changes in population health in Khabarovsk, Komsomolsk-on-Amur and other settlements due to very few stations for ambient air quality monitoring; the list of significant pollutants also need clarifying [34]. Over the analyzed period, mortality rates grew in five districts in the region where forest fires occurred constantly but similar growth was not identified in other regions. Still, no relationship was established between this indicator and the size of fire sites [35].

A review [36] summarizes data on short-term health impacts of wildfire emissions reported in few studies on the issue that were published in the USA, Europe, Australia, some Asian countries and South American countries. We have not found any similar works with data on Russia or African countries and hope that this review can fill in this gap to a certain extent. The analysis covered such health measures as emergency department visits and hospital admissions for cardiorespiratory diseases. Despite the heterogeneity among exposure and health assessment methods, all-cause mortality, and specific-cause mortality were significantly associated with wildfire emissions in most of the reports. Globally, a significant association was found for all-cause respiratory outcomes including asthma, but mixed results were noted for cardiovascular-related effects. For the latter, estimates were only significant several days after wildfire emissions and this should be taken into account when organizing health monitoring in similar situations.

Abroad, similar investigations are mostly conducted in Brazil where premature deaths grew by 9800 cases during strong forest fires

[5] Elfimova T.A. Otsenka vliyaniya emissii ot lesnykh pozharov na ekologicheskoe sostoyanie urbanizirovannykh territorii [Assessment of effects produced by emissions due to forest fires on the ecological situation on urbanized territories]: the abstract of the dissertation … for Candidate of Biological sciences degree. Orenburg, 2014, 21 p. (in Russian).

[6] Elfimova T.A., Rukavishnikov V.S., Ivanov A.G., Efimova N.V. Kachestvo atmosfernogo vozdukha i obrashchaemost' naseleniya g. Chity za skoroi meditsinskoi pomoshch'yu v period massovykh lesnykh pozharov [Ambient air quality and emergency calls in Chita during mass forest fires]: the certificate of state registration issued for the database No. RU 2015621824 of the Russian Federation, No. 2015621350; submitted on November 02, 2015, published on December 28, 2015 (in Russian).

in 2012 [37]. Especially strong fires were observed in summer 2019 in the Amazonian region when many ecosystems were lost and smoke could be traced up to 1000 km away [38]. Approximately 10 % of excess mortality on the territory was associated with smoke gases of forest fires and directly with $PM_{2.5}$ exposure; people who lived in the leeward site suffered most. Fire activity and smoke propagation distance were estimated using both satellite data and geochemical methods based on soil analysis. $PM_{2.5}$ exposure caused 4966 premature deaths in Brazil during the 2019 fire-hazardous season. That year, mortality associated with fires grew by 74 % against its 2018 level but still was a bit below its highest levels over the analyzed period (5273 deaths in 2017). However, a meta-analysis of published data on $PM_{2.5}$ impacts established greater influence on premature deaths under low levels of such particles in regions that were far from fire sites [39]. Approximately 10 % of $PM_{2.5}$-associated all-cause mortality was contributed to forest fires all over Brazil between July and September. Since the dry season usually ends in November in the Amazon River Basin, smoke emissions of fires might have played even a greater role in 2019 than estimated in the study. Apart from mortality, fires in 2019 were associated with a greater number of hospital admissions for respiratory diseases, primarily among younger children and elderly persons [40, 41].

Some very interesting results were reported in a study that investigated impacts exerted by fires of various intensity on mortality in Athens, the city population being 3 million people [42]. Those fires affected much smaller areas than in Siberia or Far East but, even being medium-sized, they were associated with an increase of 4.9 % (95 % CI: 0.3–9.6 %) in the daily total number of deaths, 6.0 % (95 % CI: -0.3–12.6 %) in the number of cardiovascular deaths and 16.2 % (95 % CI: 1.3–33.4 %) in the number of respiratory deaths. To give an example, we would like to provide data on a growing number of deaths associated with only one large-sized fire: 49.7 % (95 % CI: 37.2–63.4 %), 60.6 % (95 % CI: 43.1–80.3 %) and 92.0 % (95 % CI: 47.5–150.0 %). Interestingly, the authors of this study did not deem these effects to be associated only with growing ambient OM levels and mentioned possible effects of other factors, for example, severe stress.

Incidence. In summer and autumn 2018, the fire-hazardous season in Khabarovsk Krai was 13 days longer than its average long-term duration and the number of large fires was 1.5 times as high than average. As a result, more than 2.5 million hectares of forests were either destroyed or severely damaged [43] and smoke pollution occurred in ambient air in Khabarovsk, Komsomolsk-on-Amur and Amursk. Single maximum levels of pollutants were 6 times higher than MPL for particulate matter and 2-6 times higher for carbon oxide and sulfur dioxide in ambient air in these cities during the strongest wildfires. This situation made it necessary to examine outcomes of forest fires for population health in Khabarovsk Krai; they were investigated by various departments of the Far East Medical University in cooperation with the Rospotrebnadzor Khabarovsk Regional office, Rosgidromet, and some scientific institutions. The results obtained by these studies are summarized in the monograph *Forest Fire Smoke and Health* [33] and other publications [44]. A rise in respiratory diseases should be expected in population exposed to forest fire smoke; this trend was identified in Nikolaevskii district, which was located in a zone with strong fires, as well as in Komsomolsk-on-Amur. Cases of ‘peculiar reverse acute pathology’, which the authors called ‘toxic bronchopneumonia’, were detected in children in Khabarovsk who spent a lot of time outdoors [45]. In addition to that, the number of hospital visits for exacerbated bronchial asthma grew among children on these territories during forest fires. A similar situation was observed in Ulan-Ude. Buryatia is also among the RF regions with the highest fire hazard. Ulan-Ude, just like Chita, is located in a hollow between mountains where dispersion of smoke gases and pollutant emissions in ambient air is very slow [46].

Growing numbers of bronchial asthma cases and cardiovascular diseases were also reported during forest fires in Portugal in 2017 [28]. The results obtained indicated that the smoke from wildfires negatively impacted children's lung function (PM_{10} exposure: increase of 320 and 648 cases of bronchitis in 2016 and 2017; NO_2 exposure: 24 and 40 cases of bronchitis symptoms in asthmatic children in 2016 and 2017) [47]. Approximately 25 % of school children in Brazil (more than 10 million people) are exposed to health risks due to high ambient air pollution created by forest fires [48]. Public healthcare spent 1 million euros on treatment of these diseases.

Smoke gas impacts on adults' health have been scarcely investigated, except firefighters and people who suffered from fires in buildings. Results obtained by foreign researchers have been reported in few publications that give evidence of COPD exacerbation during such situations. For example, a study assessed outcomes of exposure to forest fire smoke that was brought to Singapore by prevailing winds blowing from the Indonesian states of Kalimantan and Sumatra in 1997 [49]. Those fires occurred 500 km away from Singapore but still led to a rise in PM_{10} levels from 50 to 150 $\mu g/m^3$. This rise was significantly associated with increases of 12 % of upper respiratory tract illness, 19 % asthma and 26 % rhinitis. Supplementary findings from scanning the electron microscopic sizing of the haze particles showed that 94 % of the particles in the haze were below 2.5 micron in diameter. This emphasizes the significance of a pioneer study on the issue that was accomplished in Khabarovsk. It showed an authentic growth in the number of hospital visits by adults with symptoms of ARI, laryngotracheitis and acute bronchitis against the same period of the season without forest fires [33]. Another confirmation of these conclusions can be found in a work by N.V. Baranovskii with colleagues [50] about frequency of bronchial asthma attacks per questioning results obtained among adults using the ECRHS international standard [51] on three types of territories that were differently affected by forest fires[7]. Statistical analysis established an authentic increase in asthma-like symptoms on areas affected by forest fires. The authors did not mention the exact area where the study was conducted but we can assume it to be Tomsk region.

Negative impacts of ambient air polluted with forest fire smoke have been confirmed by a series of studies conducted in California; they remain significant health risk factors, especially for the most vulnerable population groups. More than 30 million hospital visits were analyzed representing a gigantic sample of data on healthcare services provided in 2008–2016 for asthma, COPD, respiratory and cardiovascular diseases including myocardial infarction and essential hypertension. As a result, higher risks were established for asthma and respiratory symptoms in comparison with cardiovascular diseases. Health risk assessment also considered a person's age and socioeconomic status and health risks turned out to differ significantly between different demographic groups.

Adults were examined in Khabarovsk Krai during forest fires. As opposed to children, they tended to have authentic impairments of the CNS and cardiovascular system as evidenced by growing numbers of hospital visits for coronary heart disease, essential hypertension and myocardial infarction [33]. Professor T.A. Zakharycheva, a co-author of this monograph, believes that 'there is practically no information about impacts of smoke gases from forest fires on the CNS' but patients with dyscirculatory and post-stroke encephalopathy who were treated in neurological hospitals in Khabarovsk and Komsomolsk-on-Amur tended to have decompensated state or transient ischemic attacks during forest fires. Patients with osteochondrosis, predominantly cervical spine one, had acute

[7] Bronkhial'naya astma [Bronchial asthma]: monograph in 2 volumes. In: RAMS Academician A.G. Chuchalin ed. Moscow, Agar Publ., 1997, vol. 1, 432 p. (in Russian).

vertebrobasilar insufficiency that manifested itself through vestibulocerebellar syndrome. The number of patients hospitalized for cerebrovascular pathology grew by 1.4–4 times ($p < 0.01$–0.001) and frequency of acute strokes grew by 1.2–4.5 times ($p < 0.01$–0.001) in a year with intensive forest fires against the previous one. The authors of this study, who are neurologists from the Far East State Medical University, believe that 'a large role in pathogenesis of cerebral ischemia is played by changes in the physiochemical state of blood resulting from exposure to toxic combustion products and having considerable impacts on cerebral hemodynamics'. In addition to that, many chemicals that are formed during fires affect various biochemical indicators, for example, lipid peroxidation [44]. This was confirmed in field conditions by research results obtained for people living in a district in Khabarovsk Krai, which was exposed to smoke from forest fires. Identification of lipid peroxidation markers and markers of antioxidant protection established signs of elevated cytolysis in one third of examined people, namely, higher levels of alanine aminotransferase (ALT) and alkaline phosphatase. The authors believe this 'might result from the lung fraction of blood entering the circulation upon inhaling toxic components in smoke able to damage cellular membranes of the respiratory airways and alveoli' [52].

A series of studies was conducted in Khabarovsk Krai to estimate effects produced by ambient air pollution due to wildfires. Among other things, it included reproductive health assessment. Pregnant women's health tended to deteriorate during periods when pollutant levels were the highest in ambient air; there was a growth in extragenital pathology detected in Komsomolsk-on-Amur during forest fires in 2018. An authentic increase in gestation and a trend towards blood hypercoagulation was established in exposed population in comparison with controls [33]. Reproductive health impairments associated with effects of long wildfires have also been reported in foreign publications [36].

Difficulties in timely extinguishing of forest fires are to a certain extent associated with closing down such an agency as the State Forest Guard. It was re-established several years later but experienced and valuable personnel had been lost. Areas with burning forests where fires were being extinguished reached 107 thousand hectares in 2019. The second problem is that some control zones are located in areas without any settlements and in case of fire only video monitoring is provided and not extinguishing. The situation with forest management is deemed 'deplorable' in the country [7] since sufficient financial support is not provided for proper forest protection and the existing agency cannot cope with the task.

In Russia, just as in any other country, several population groups are the most susceptible to effects of forest fires including people older than 65 years, people with chronic cardiorespiratory diseases, pregnant women and children who often fall sick. In cities, especially those with population above one million, special attention should be paid to elderly people and homeless people during periods of high air temperatures above the temperature threshold [19, 53] and during forest fires. Even if notification about coming heat and forest fires has been delivered in due time, some people from risky groups cannot take protective measures. Therefore, authorities, social organizations and volunteers should provide such people with drinking water, medications, and food. Demographic forecasts in Russia indicate a further growth in the share of people older than 65 years in the age structure of the country population. Given that, special attention should be paid to this population group by the whole social sector. The results obtained by studies conducted in the USA and Canada show that if short-term outcomes of PM exposures are taken into account, overall health impairments due to forest fires turn out to be even greater than expected [54–56].

This review concentrates on health risks caused by effects of forest fires. But there is another urgent issue, namely, health risk as-

sessment in situations when fires occur at household waste landfills, which typically contain huge quantities of various polymer materials. Smoke gases from fires at such objects contain volatile organic compounds, styrene, butylene, acetaldehyde, acetic acid, and other toxic chemicals. They can become pollution sources and be detected in ambient air at a considerable distance away form a fire site [57]. Smoke gases from wildfires can contain radioactive substances as well; for example, $_{127}$Cs often occurs in areas with radioactive pollution. The major part of this isotope is emitted into ambient air from burning forest floor [58]. This should be considered when planning control or scientific research on such territories.

Another serious issue is absence of any medical information for people how they should behave during abnormal heat and forest fires and either for decision-makers as regards what actions they should take in such situations. This has extremely negative impacts on human health. For example, in 2010 in Moscow, clinicians and experts in preventive medicine used to issue very controversial recommendations for population. In 1998 in Khabarovsk, people were recommended 'to use oxygen bags' during forest fires and heavy smoke pollution in ambient air. This might have enhanced negative impacts and resulted in oxidative stress caused by pollutants [33].

When analyzing the situation with forest fires in the country, some legal experts point out gaps both in the state legislation and in the very system for forest management in their publications. In their opinion, the Forest Code of the Russian Federation does not establish specific requirements to people, who extinguish forest fires; there is no effective regulatory legal base for protecting forests from fires; the state regulation in the sphere has some other drawbacks [59]. Some faults in legal documents on forest protection are also mentioned by a legal expert M.V. Oleynik [60], who insists on existence of several problems including illegal lumbering, illegal wood exports, absence of proper control over the forest fund and a unified information system. At the same time, there are some positive examples of implementing a video monitoring system around forests in Perm Krai. This made it possible for the Forest Guard to react in due time and take necessary measures aimed at localizing a fire and preventing smoke gases from spreading onto densely populated residential areas.

Experts from the Central Scientific Research Institute on Civil Defense and Emergency Situations of the Ministry of Emergency Situations of the Russian Federation believe it is necessary to implement a hardware-software complex Safe City into municipal management structures. This complex allows developing models for middle-term and long-term prediction of forest fires based on the analysis of historical data on meteorological conditions, fire hazard, forest fires, and other indicators [61]. Such a database and prediction scenarios are likely to be useful for Rospotrebnadzor regional offices within assessment of a sanitary-epidemiological situation on a given territory and development of relevant preventive activities during forest fires.

Experience gained by BRICS countries may be of interest since they regularly suffer from huge forest fires and therefore investigate health outcomes of this natural disaster and estimate economic losses caused by ambient air pollution in residential areas. In a study [62], the authors used a combination of regional and global air quality models and observations to examine the impact of forest and vegetation fires on air quality degradation and public health in Southeast Asia. They found that eliminating fire could substantially improve regional air quality by reducing the population exposure to fine particulate matter ($PM_{2.5}$) concentrations by 7 % and surface ozone concentrations by 5 %. These reductions in $PM_{2.5}$ exposures would yield a considerable public health benefit across the region averting 59,000 (95 % uncertainty interval (95 CI): 55,200–62,900) premature deaths annually. The authors conclude that reducing forest and vegetation fires should be a public health priority for the Southeast Asia region.

It is quite advisable to conduct a similar study for the most fire-hazardous Russian territories. It is necessary to reinforce monitoring of respiratory incidence among population, especially children, in action plans of healthcare organizations in areas exposed to smoke from forest fires and to include relevant preventive activities in them. Relevant agencies and institutions should organize control of ambient PM levels and develop models considering a temperature of smoke gases and PM spread as a key indicator of such gases towards densely populated residential areas.

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