Carcinogenic hazard of forest fires for the atmosphere of the Irkutsk region cities

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Abstract. In the paper, we compared the dynamics of the carcinogenic benzo(a) pyrene content in the atmospheric air of cities and the rates of forest fires in the territory of the Irkutsk region for the period 1987-2015. We found positive linear dependencies between the mean concentrations of benzo(a)pyrene in the atmosphere and the intensity of fires. It was shown that the accuracy of correlations is higher for the last 10-15 years, which may indicate an increase in the contribution of wildfires to atmospheric pollution as compared to other sources.

1. Introduction

Most cities in the Irkutsk region are characterized by a high level of air pollution with hazardous substances. Among them, a significant proportion belongs to carcinogenic benz(a)pyrene (B(a)P) [1, 2], an indicator of the priority persistent organic pollutants of the polycyclic aromatic hydrocarbons (PAH) group. These compounds are formed in the processes of incomplete combustion and pyrolysis of organic materials, the sources of which are enterprises of various industries. Along with man-made sources, their sources also may be natural forest fires, which were estimated by the formation of carcinogenic PAHs in a number of foreign studies [3-5]. There have been papers to estimate the impact of hazardous components, including B(a)P, from forest fires on the atmosphere using the example of the Irkutsk region [6]. At the same time, there is no convincing evidence about the contribution of forest fires to urban pollution.

The purpose of the work is to study forest fires as a source of atmospheric pollution with carcinogenic benzo(a)pyrene in the cities of the Irkutsk region.

2. Materials and methods

The paper studies the results of monitoring the B(a)P content in the atmosphere of 10 cities of the Irkutsk region, which differ in the presence of various industries and are characterized by a uniform distribution throughout the densely populated territory of the region. In the paper, we considered two indicators for assessing the content of the substance in the atmosphere. These are the average annual concentration $\bar{C}_{BP}$ (ng/m^3) in MAC fractions (1 ng/m^3) and the standard index $\bar{SI}_{BP}$ (ng/m^3) as the maximum monthly average concentration, also in MAC fractions. We used the data given in the Yearbooks of Roshydromet [7] for the observation period 1987-2015. For the same period of time, we analyzed the annual statistics of fires in the territory of the Irkutsk region according to the reports of the Fire Statistics Center of the International Association using two indicators of forest fires: number of fires per year (*N*) and area covered by fire (*S*, ths. ha). The results were processed using the method

of correlation analysis, calculating the correlation coefficients of linear dependencies r_{xy} for significance levels α and the number of degrees of freedom f equal to n - 2, where n is the number of observations.

3. The results of the study and their analysis

In the territory of the Irkutsk region, there are the largest enterprises of power engineering, oil refining, non-ferrous metallurgy, chemical and petrochemical and other industries that are sources of carcinogenic PAHs and B(a) P emissions into the atmosphere. An additional contribution to air pollution is made by motor vehicles, a large number of small boiler houses, and the residential sector with furnace heating. Monitoring of the B(a) P content in the atmosphere has been carried out since 1987. Currently, there are 29 pollution surveillance points in 16 cities. For the 10 most polluted of them, we indicate the $\bar{C}_{BP}$ and $\bar{SI}_{BP}$ content in MAC fractions of the substance in dynamics with a 5-year interval (Table 1).

Table 1. Dynamics of the benzo(a)pyrene content in the atmospheric air of the Irkutsk region cities.

	Observation year					
	1990	1995	2000	2005	2010	2015
City (primary production)	average annual (maximum monthly average) concentrations of benzo(a)pyrene, MAC fractions (1 ng/m^3) [7]					
Angarsk (petrochemistry)	4.2	3.9	2.0 (5.1)	4.0 (7.8)	2.6 (6.8)	1.2 (3.6)
Irkutsk (heat power engineering)	9.6	7.7	1.4 (5.2)	3.0 (5.2)	4.2 (10)	1.5 (9.2)
Usolye-Sibirskoye (chemistry)	2.5	4.3	2.6 (15.7)	2.7 (5.5)	2.6 (5.6)	3.8 (8.4)
Sayansk (chemistry)	0.7	0.2	0.7 (1.5)	2.0 (3.9)	1.5 (2.5)	2.0 (4.9)
Ust-Ilimsk (forestry)	0.7	0.7	1.7 (2.8)	2.7 (6.2)	1.9 (3.6)	0.5 (2.0)
Bratsk (aluminium)	11.1	6.2	2.5 (13.9)	2.9 (7.5)	5.1 (11.4)	6.7 (30.2)
Shelekhov (aluminium)	12.4	12.9	2.2 (5.3)	2.8 (5.7)	2.8 (6.2)	3.3 (9.3)
Zima (agriculture)	13.1	8.2	2.2 (1.7)	3.5 (6.5)	3.7 (8.0)	6.6 (39.6)
Cheremkhovo (coal)	11.4	8.2	1.8 (4.4)	3.8 (7.5)	2.3 (4.1)	1.9 (3.8)
Baikalsk (agriculture)	0.7	0.7	1.7 (2.8)	2.7 (6.2)	1.9 (3.6)	0.5 (2.0)

Analysis of average annual and maximum contents of B(a)P in the atmosphere shows concentrations above MAC with a variation from 1.2 to 13.1 and from 1.5 to 39.6, respectively. In the average annual values of $\bar{C}_{BP}$, there is a tendency to reduction of the degree of atmospheric pollution by the carcinogen over a 25-year period of time by about 2-4 times. The maximum values of the SI_{BP} indicator vary little, as evidenced, for example, by high and comparable pollution levels in both the industrial city of Bratsk and the agrarian city of Zima. The general downward trend is due to the decline in production and the emergence of more "environmentally friendly" technologies, for example, in heat power engineering and aluminum production.

During the study period, we saw a high level of forest fires in the region persisting, which is confirmed by their indicators shown in Figure 1.

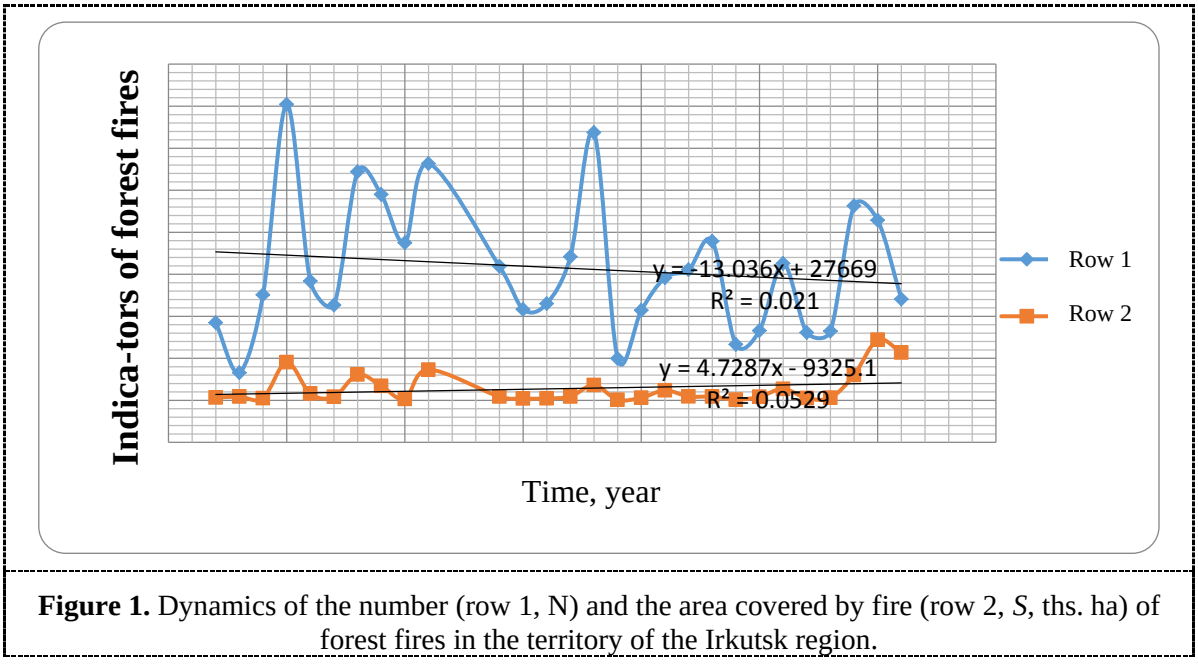

Figure 1. Dynamics of the number (row 1, N) and the area covered by fire (row 2, *S*, ths. ha) of forest fires in the territory of the Irkutsk region.

One should note the cyclic recurrence of fires, which after 2000 occurred also in 2003, 2008 and 2014. Whereby there is a positive correlation between the two indicators of the number of fires N and their area S for the period 2000-2014 (r_{xy} = 0.754, α = 0.01).

A fairly uniform spread of fires across the region suggests the same distribution of B(a)P emissions, which can be more accurately expressed in terms of averages $\bar{C}_{BP}$ and $\bar{SI}_{BP}$ obtained from the annual observations for the 10 cities studied and presented in Figure 2.

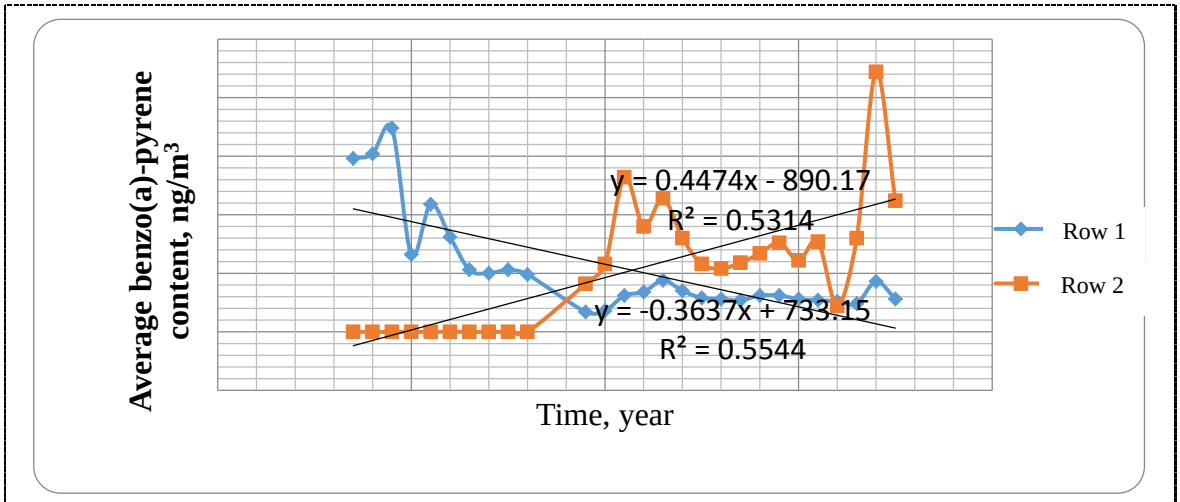

Figure 2 . Dynamics of mean values of average annual (row 1, $\bar{C}_{BP}$, ng/m^3) and standard indices (row 2, $\bar{SI}_{BP}$, ng/m^3) of the benzo(a)pyrene content (MAC fractions) in the atmospheric air of 10 cities (see Table 1) of the Irkutsk region.

In Figures 1 and 2 one can see the synchronism between the two indicators with clearly distinguished maxima in 2003 and 2014 in terms of the number of fires and the B(a)P content in the atmosphere. The dependencies of the average B(a)P contents in the atmosphere of cities in the region on the intensity of fires also confirm the statistically significant positive linear correlations both for the indicator of the number of forest fires and for the area affected during the fire (Table 2).

Table 2. Accuracy of linear dependencies of mean values ($\bar{C}_{BP}$, $\bar{SI}_{BP}$) of the average annual benzo(a)pyrene content in the atmosphere for 10 cities in the Irkutsk region on indicators of forest fires in different periods of time.

Observation period	Correlation coefficients, r_{xy} (α, f)	
	$\bar{C}_{BP} = f(N)$	$\bar{C}_{BP} = f(S)$
1987-2015	insignificant	insignificant
1987-1996, 1999	– 0.537 (0.10; 9)	insignificant
2000-2015	+ 0.594 (0.02; 14)	insignificant
2000-2014		+ 0.637 (0.02; 13)
2005-2014		+ 0.780 (0.01; 8)
	$\bar{SI}_{BP} = f(N)$	$\bar{SI}_{BP} = f(S)$
1999-2015	+ 0.466 (0.10; 15)	
2005-2015	+ 0.620 (0.05; 9)	
1999-2014		+ 0.735 (0.01; 14)
2005-2014		+ 0.865 (0.01; 8)

Note α – significance level; f – number of degrees of freedom equal to $n - 2$, where n – number of observations; N – number of forest fires; S – area covered by fire, ths. ha; $\bar{C}_{BP}$ – mean concentration of average annual and $\bar{SI}_{BP}$ – average standard index (*SI*) of maximum monthly average B(a)P concentrations in 10 cities of the Irkutsk region.

Analysis of the values of the correlation coefficients reveals the following features.

First, the lack of relations for the early observation period of 1987–2000 and even a negative correlation, when it is impossible to draw a conclusion about the effect of fires on atmospheric pollution by carcinogenic PAHs.

Second, for the period after 2000, a positive correlation is observed. Moreover, its accuracy has increased in the last 10–15 years. Such a pattern may be due to the fact that, the contribution of fires to the atmospheric pollution of cities in the region is more clearly manifested against the background of reducing B(a)P emissions by traditional man-made sources. The degree of accuracy can be estimated by the values of the significance level, a decrease of which indicates closer relations between the indicators.

Third, it should be noted that the dependencies obtained approximately equally reflect the two indicators both in terms of the B(a)P content in the atmosphere and in terms of the forest fires indicators.

4. Discussion

The problem of air pollution in the cities of the Irkutsk region with hazardous substances, among which carcinogenic ones, for example, B(a)P, are of priority importance, presents with a need to identify the sources of pollution. To date, more complete information is available on relatively organized stationary sources of large enterprises and industries. At the same time, over the past two decades, in addition to the decline in production, there have appeared technologies with a predominance of those that have better ecological characteristics. The result is a general tendency for

the decarcinogenization of the atmosphere in recent years compared with the end of the last century. However, hazardous levels of B(a)P in the atmosphere still persist, especially by its maximum values (see Table 1). This dictates the need to identify sources of PAH formation. Taking into account the fact that they are formed in the processes of burning forest plant materials, it is necessary to evaluate forest fires as sources of emissions of these substances. Having studied the dynamics of $\bar{C}_{BP}$ and $\bar{SI}_{BP}$ values of atmospheric pollution in the most populated cities of the Irkutsk region with carcinogenic B(a)P we revealed the highest values in 2003, 2004 and 2014, which corresponded to the dynamics of forest fires intensity. We found statistically significant linear positive dependencies between the indicators of the B(a)P content and the number of fires and their burning extent. Their accuracy in the values of the correlation coefficients have increased in recent years of observations (r_{xy}=0.500–0.740, α=0.05–0.01, n=15–16). This result indicates the impact and growth of the forest fires contribution against the background of other sources of carcinogenic B(a)P emissions.

5. Conclusion

Based on the results of forest fire monitoring, the B(a)P content in the atmospheric air of large industrial and agricultural cities of the Irkutsk region and dependencies obtained between them, in general, natural forest fires can be considered as a source of air pollution. In this case, it seems relevant to assess the impact of carcinogenic substances from emissions of combustion products, to continue these studies now at the level of the local effects of fires and the distribution of carcinogenic substances from them in the atmosphere of cities and other populated areas.

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