Sources of carcinogenic risks for atmosphere of Irkutsk Region cities

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Abstract. In the paper, the authors compared the dynamics of the carcinogenic benzo(a)pyrene content in the atmospheric air of the Irkutsk Region cities and the cancer morbidity of the population. Further, the authors estimated benzo(a)pyrene emissions from “low” power heat sources (boiler houses and household furnaces). Dependences of the content of benzo(a)pyrene in the atmosphere of cities on its gross emissions by “small” heat sources, on the area of forest fires are found. The study showed their impact, as well as the impact of motor transport and forest fires on the state of the atmosphere of industrial and agricultural cities of the region. The authors drew a conclusion about the contribution of man-made and natural sources to the atmospheric pollution with benzo(a)pyrene, and about the need to define it and develop measures to reduce emissions.

1. Introduction

Worldwide, there is a tendency of cancer morbidity growth, which is determined by such factors as population aging, socio-economic and environmental conditions [1,2]. In 2017, in Russia about 300 thousand patients died of malignant tumors, which is 15.9% in the overall structure of mortality (the second cause after cardiovascular diseases). The increase in this indicator compared to 2016 amounted to 3.0% [3]. For the population of the Irkutsk Region, the increase was similar and equal to 2.8%. The leading position (up to 12%) was taken by skin cancer, followed by cancer of respiratory organs and organs of the gastrointestinal tract. The indicated problem confronts us with the need to identify carcinogenic factors and eliminate them. One of these factors may be the presence of chemical carcinogens in the atmospheric air. It is known that many regions of Russia [4], as well as most cities of the Irkutsk Region [5], are characterized by a high level of air pollution with hazardous substances, among which benzo(a)pyrene (B(a)P) makes a significant contribution to the integral atmospheric pollution index (API). It is a carcinogen of the 1st hazard class, an indicator of the priority persistent organic pollutants of the polycyclic aromatic hydrocarbons (PAH) group [6,7]. They are formed in the process of incomplete combustion and pyrolysis of organic materials [8-11]. It seems relevant to identify sources of B(a)P formation and its emissions into the atmosphere of cities and settlements.

The aim of the paper was to study the impact of man-made (“low” power heat sources, motor vehicles) and natural (forest fires) sources of emissions on atmospheric pollution with carcinogenic benzo(a)pyrene in the cities of the Irkutsk Region.

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2. Objects and methods of investigation
The objects of the study were 10 large industrial and agricultural cities of the Irkutsk Region, with up to 55 % of the region’s population living there. The cities are located in the Southern Baikal area and differ in types of production. The city of Irkutsk is dominated by power engineering facilities (heat and power plants, boiler houses, household furnaces); the cities of Angarsk, Usolye-Sibirskoye and Sayansk are distinguished by petrochemical and chemical industries; Ust-Ilimsk is engaged in timber processing; Bratsk and Shelekhov are notable for their primary aluminum production; the city of Cheremkhovo has coal mining enterprises; Baikalsk and Zima are small agricultural cities.

For the cities studied, we analyzed data on the population cancer morbidity for the period 2013-2016 [12], and the results of monitoring the B(a)P content in the atmosphere of the cities according to observations of Roshydromet [13] for the period 2011-2015.

We investigated emissions of carcinogenic B(a)P into the atmosphere from “low” power heat sources, which include coal-fired boiler houses with a capacity of up to 1 MW and individual household furnaces using coal and wood. The calculation of B(a)P emissions is based on the values of its specific emissions from these sources [14], taking into account the number of boiler houses, amount of individual heating and the fuel consumed by them in the cities for 2016.

The impact of B(a)P emissions into the atmosphere from motor transport during the warm season is determined indirectly using biomonitoring of tree leaves growing at different distances from highways using the example of the city of Irkutsk [15].

The impact of forest fires on the atmospheric pollution of the cities with B(a)P was studied by comparing the dynamics of the carcinogenic substance content in the atmosphere of the cities studied and the rates of forest fires in the territory of the Irkutsk Region for the period 2000-2015. We used data from the Yearbooks of Roshydromet [13] and the reports of the Fire Statistics Center on two indicators of forest fires: number of fires per year (N) and area covered by fire (S) [16].

3. Results
Over the past 20 years, the cancer morbidity of the Irkutsk Region population has had a tendency of growth and a significant excess of similar indicators in Russia. One of the factors leading to cancer diseases may be the presence of chemical carcinogens in the atmospheric air. Currently, B(a)P is controlled in the atmosphere of residential areas. Analysis of the dynamics of its average annual concentrations shows their decline from 1995 to 2-3 MACs. However, the mean values of the maximum per month range from 6 to 11 MACs (Table 1).

| Indicator | Observation year | 1995 | 2000 | 2005 | 2010 | 2015 |
|-----------|-----------------|------|------|------|------|------|
| Cancer morbidity, per 100 thousand people [3]: | | | | | | |
| Irkutsk Region | | 440 | 450 | 560 | 600 | 610 |
| Russia | | 200 | 210 | 215 | 230 | 240 |
| Mean of average B(a)P concentrations, ng/m$^3$ (or MAC fractions) | | 5.3 | 1.9 | 3.0 | 2.9 | 2.8 |
| Mean of maximum monthly average B(a)P concentrations, ng/m$^3$ (or MAC fractions) | | - | 5.8 | 6.2 | 6.2 | 11.3 |

Blank “-” – no data.
MAC - maximum allowable concentration. B(a)P MAC in the atmosphere - 1 ng/m$^3$.

The morbidity of the population and the content of B(a)P in the atmosphere of individual cities are presented in Table 2.
The possibility of carcinogenic pollution of the urban atmosphere from motor transport was assessed using the example of the city of Irkutsk by means of monitoring the leaves of woody plants for the B(a)P content [15]. We investigated the leaves of common tree species: balsam poplar (Populus balsamifera L.), silver birch (Betula pendula L.), and boxelder maple (Acer negundo L.) depending on the landscape and transport impact (Table 3).

**Table 2.** Cancer morbidity, atmospheric pollution and benzo(a)pyrene emissions from “low” power heat sources.

| City (population, thousand people) | Average (over 5 years) | B(a)P emissions, t/year |
|------------------------------------|------------------------|------------------------|
| Morbidity, per 100 thousand people | B(a)P content in the atmosphere, ng/m³ | boiler houses (up to 1 MW) | household furnaces |
|------------------------------------|------------------------|------------------------|
| Irkutsk (624)                      | 475                    | 3.1* (13.7)**          | 0.088                  | 0.334 |
| Bratsk (232)                       | 453                    | 5.4 (26.4)             | 0.020                  | 0.067 |
| Angarsk (226)                      | 506                    | 1.9 (6.5)              | ~ 0                    | 0.047 |
| Ust-Ilimsk (82)                    | 452                    | 1.1 (3.0)              | 0.020                  | 0.020 |
| Usolye-Sibirskoye (78)             | 472                    | 3.2 (9.7)              | 0.027                  | 0.092 |
| Cheremkhovo (51)                   | 455                    | 2.1 (4.6)              | 0.068                  | 0.294 |
| Shelekhov (50)                     | 475                    | 3.7 (13.4)             | 0.007                  | 0.013 |
| Sayansk (39)                       | 464                    | 2.0 (6.1)              | ~ 0                    | 0.0001 |
| Zima (31)                          | 391                    | 5.6 (24.7)             | 0.041                  | 0.142 |
| Baykalsk (13)                      | 455                    | 1.0 (2.4)              | ~ 0                    | 0.007 |

* - annual average concentration.
** - maximum monthly average concentration.

**Table 3.** Benzo(a)pyrene accumulation by leaves of trees growing at different distances from the highways of Irkutsk.

| Remoteness from highways (for central streets of Irkutsk) | Mean B(a)P concentration, mkg·kg⁻¹ (n - the number of samples) |
|----------------------------------------------------------|---------------------------------------------------------------|
|                                                          | birch, poplar and maple leaves (without and with external pollution) | poplar leaves (without external pollution) |
| 3 m away from highways                                   | 13 ± 9* (n=11)                                                 | 14** (8–25, n=14) |
| 5 m away from highways                                   | 8 ± 5 (n=22)                                                   | 11 (8–12, n=15) |
| 15-20 m away from highways                              | 6 ± 3 (n=10)                                                   | 10 (7–12, n=10) |
| Courtyards and squares                                   | 7 ± 3 (n=16)                                                   | 9 (8–12, n=23) |
| Reference site (for birch and poplar)                   | 3.0 ± 2.0 (n=19)                                               | 3.0 (1-5, n=15) |

* Arithmetic mean ± standard deviation.
** Average (minimum - maximum).

Along with the considered man-made sources of B(a)P emissions into the atmosphere of the cities, such as “small” heat power engineering and motor transport, there are also natural sources. These include forest fires, which are processes with the formation of incomplete combustion products including B(a)P and PAHs. Therefore, we studied forest fires as possible sources of B(a)P entering the atmosphere of the Irkutsk Region cities. The study consisted in comparing the dynamics of forest fires
rates and the average B(a)P content in the atmospheric air of 10 cities in the southern part of the Irkutsk Region for the period 2000-2015.

4. Discussion

For all the cities, the cancer morbidity varies relatively in a small range of values from 391 to 506 cases per 100 thousand people. In terms of the B(a)P content in the atmosphere, only in the city of Baikalsk, the average annual concentration over five years does not exceed MAC. In other cities, this figure varies from 2 to 5.6 normal values, and the maximum per month - from 3 to 26.4 MACs.

First of all, it is worth highlighting the cities of Bratsk and Shelekhov, where high concentrations of B(a)P in the atmosphere have always been observed [13]. In the paper [17], authors studied the composition of carcinogenic PAHs in the snow cover of the city of Bratsk. On the example of the Irkutsk aluminium smelter, located in the city of Shelekhov, the mass emissions of B(a)P and its analogues were estimated depending on the production technology [18].

The high B(a)P content in the atmosphere of other cities, especially non-industrial city of Zima, confronts us with the need to identify B(a)P emission sources. Predominantly, these are 1005 “low” power boiler houses up to 5 MW and individual heating furnaces, which burn coal and firewood using a stratified method with active formation of incomplete combustion products - carbon monoxide, B(a)P and other PAHs, soot [14]. From the statistical reporting on the heat supply of the Irkutsk Region in the period 2015-2017 [19], we took into account the quantities and types of fuel consumed for “small” boiler houses and individual houses for the selected cities. Taking them and specific B(a)P emissions into account [14], we calculated gross emissions of the carcinogen per year separately for boiler houses and household furnaces (Table 2). From the presented results it can be seen that the minimum gross emissions of B(a)P from “low” power heat sources were identified in small industrial cities - Sayansk and Baikalsk, and large industrial ones - Angarsk, Bratsk, Shelekhov. For the 6 cities, we found a statistically direct link between atmospheric pollution and gross B(a)P emissions.

It was found that the degree of tree leaves contamination determines the place of green planting - when moving away from highways there is a regular decrease in the B(a)P content regardless of the plant species, with the minimum level of pollution in trees growing in courtyards and squares (Table 3). The result obtained allows us to consider motor transport as a source of plants pollution and the atmosphere associated with them during the summer period.

Uniform scatter of forest fires predominantly in the southern territory of the region suggests the same distribution of combustion products, in particular B(a)P. Therefore, it was more accurate to express its concentration as the average value obtained from annual observations for the 10 cities studied. The dynamics of these mean average annual B(a)P concentrations in the atmosphere of the cities highlights 2003, 2008 and 2014, which are consistent with the peaks of forest fires [20]. The dependencies of the average B(a)P contents on the intensity of the fires are also confirmed by positive correlations for both indicators N and S (Table 4).

| Observation period | Correlation coefficient, \( r_{xy} (\alpha, f) \) | \( \bar{C}_{BP} = f (N) \) | \( \bar{C}_{BP} = f (S) \) |
|--------------------|---------------------------------------------|----------------|---------------------------------|
| 2000-2015          | + 0.594 (0.02; 14)                          | insignificant |                                  |
| 2000-2014          | + 0.637 (0.02; 13)                          |                |                                  |
| 2005-2014          | + 0.780 (0.01; 8)                           |                |                                  |

\( \alpha \) - 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, thnd ha.

\( \bar{C}_{BP} \) - mean concentration (ng/m³) of average annual B(a)P concentrations in 10 cities of the Irkutsk Region.
Analysis of the values of the correlation coefficients \( r_{xy} \) shows that the accuracy of the relationships has increased in the last 10 years, which can be explained by the fact that, against the background of reduced emissions from man-made sources of pollution, the contribution of fires to the atmospheric pollution is increasing. Based on the results of forest fire monitoring and the B(a)P content in the atmosphere of the southern Irkutsk Region cities, we identified relationships that make it possible to consider forest fires as natural sources of carcinogenic B(a)P emissions.

5. Conclusion

The problem of increasing cancer rates among the population and atmospheric pollution in most cities of the Irkutsk Region with carcinogenic substances, in particular B(a)P, confronts us with the need to identify emission sources. Their monitoring predominates for organized stationary sources of large enterprises and industries. At the same time, estimates of B(a)P emissions are practically unknown for “small” heat power engineering sources, transport systems, and fires. The various methods and methodological approaches applied in this paper to direct or indirect calculations of the B(a)P amount and impact on the atmospheric air from man-made and natural burning of combustible materials have shown the possible contribution of boiler houses, household furnaces, motor transport, and natural forest fires to the atmospheric pollution of industrial and agricultural cities of the Irkutsk Region.

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