Biomonitoring of Air Condition in Urban Environment (with Regard to Irkutsk, Irkutsk region in Russia)

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Abstract. The paper deals with the results of investigation into the contents and distribution of cancer-causing benzo(a)pyrene in the leaves of the trees that are common in the urban environment of Irkutsk. The degree of plant pollution is determined depending on the landscape and traffic exposure, on the mode of the plant material being prepared and on its type. The methodology for landscape geochemical biomonitoring is offered to be used at the stages of sample sorting and preparation and in the statistical treatment of the analysis results obtained. The possibility to use tree leaves as biotest materials for the urban atmosphere state control is considered in the paper.

1. Introduction
The significance of the ecological problem resulting from chemical pollution of the atmosphere of great towns and metropolitan cities claims for a necessary assessment of its quality. A landscape-geochemical analysis is an informative method of an air condition monitoring of the urban ecological systems [1,2]. The method under consideration allows to study the distribution of pollution agents in separate components of the urban landscape [3-5] and also to reveal the zones and sources of their pollution. At present it is established that motor transport contributes most to the pollution of urban atmosphere, making up from 50 to 90 % of the total emission performed by different sources of the atmosphere pollution [6-9]. Its affect is particularly great in the summer period when the emissions of heating systems get decreased. Among detrimental components of vehicle exhaust gas, carcinogenic polynuclear aromatic hydrocarbons are of a great danger. Their indicator is benzo(a)pyrene, (B(a)P), certifying their availability with regard to Russian science. According to the official data [10], B(a)P makes up a considerable portion of the integral index of the atmosphere pollution of Russian cities many of which are included into the list of cities with a high level of atmosphere pollution, Irkutsk from Irkutsk region being found in this list. At present, Irkutsk is characteristic for a constant growth of a wheeled transport park, their influence on the town atmosphere being not studied sufficiently.

The purpose of the work is the investigation into the atmosphere of the town of Irkutsk with regard to landscape-transport exposure, B(a)P being determined basing on the method of biomonitoring [11-14] woody plant leaves.

2. The territory, objects and methods of investigation
The town of Irkutsk is located on the Southern platform margin. The most part of its relief is greatly compartmentalized by river-valleys of the rivers of Angara, Irkut and their tributaries. On the territory
being considered a flood-plain terrace (0.75–2.5 m.), the first one above the flood-plain (4–8 m.), the second (10–15 m.), the third (16–20 m.) and the high fourth (20–25 m.) terraces are distinctly seen as the ones forming a geomorphic river profile. Hill slopes are above the terraces.

The climate is sharply continental [15]. A yearly precipitation is 350–430 mm. A yearly average temperature is 1.1 °C. Temperature inversions are quite common in winter along with a simultaneous “steaming” of Angara-river open water below the dam of the Irkutsk HEP. The weather conditions being unfavourable, this factor facilitates the appearance of smog. A high frequency of a “dangerous wind velocity” occurrence for low emissions is registered in Irkutsk. The most unfavourable conditions are formed in a lower layer which is 20 meters thick in connection with concentrating a considerable portion of emissions here: vehicle exhaust gases, industrial enterprises wastes. A high level of atmosphere pollutions and climate peculiarities call into being unfavourable conditions for residence in some regions of Irkutsk. To assess the atmosphere pollutions of the town in its warm season of the year green planting of trees were chosen intended for city-wide use along thoroughfares and in the yards, located in different regions of the town (Figure1).

Figure 1. Sites of tree leave tests (s.t.) to be selected on the territory of the town of Irkutsk: s.t. 1 – terrace 4 above the flood-plain (a yard in Stanislavsky Street); s.t. 2 and 5 – a hill slope (some yards and a road across Yubileiny housing complex); s.t. 3 and 6 – terrace 3 above the flood-plain (the yards in Akademgorodok and Lermontov Street); s.t. 4 – is a floodplain of the river (a dam, a lower reach); s.t. 7 is terrace 4 above the flood-plain (Baikalski Street). The scale is 1: 100 000.

Hard wood trees are very common in landscape gardening activity of Irkutsk [16]: rough-bark poplar (*Populus balsamifera* L.), drooping birch (*Betula pendula* L.), sugar maple (*Acer negundo* L.). Benzo(a)pyrene, a cancer-causing element of the 1st class danger is found in their leaves. A leaf is a basic accumulating member of a plant and an object showing the state of atmosphere and soil. To reveal the role of gardening leaves in B(a)P accumulation challenges were set to reveal species specificity of plants aimed at determination of accumulation ability that are characteristic for the compounds in an urban environment as compared with the natural (background) territory.

The methodology of leaves test selection [17] was brought into balance with the urban environment conditions. Test plots were laid foundations of on the terraces along the river in the important streets of the town. They located in the correspondence with the geomorphological profile of the river and had changing parameters of the environment from the water-level to the hillslope. The length of each plot made up 1km. An average representative leaves test of 2 kg raw weight each was selected along a plot. Tests were also selected on each plot at the distance of 3m, 5m and 15–20 m from the traffic way border and in the yards of 4–9 storey housing development. The time of selection is August, late summer season when assimilation organs of plants contain the maximum amount of pollution agents.

Test preparation of a half of its plant material included washing off its silt in the flow cold water for 10 minutes, rinsing with distilled water, drying in the air in a dark place until the tests become of an airdry condition. The dried plant material, both washed and unwashed from outer contamination
was disintegrated separately until it acquired a powder condition, the average test of 200 g in mass being kept in paper packets in a dark, cool, dry place.

The mass concentration of B(a)P in the hard wood leaves was determined by the method of low temperature luminescence at the boiling temperature of liquid nitrogen (77 K) in n-octane using a fluorescent spectrophotometer, Hitachi 650-10 S (Japan), the methodology being certified one [18]. The error of B(a)P determination varied from 20 to 50 % in the range of 0.5–2500 µg kg⁻¹ of an agent, confidential probability being P=95% with the detection threshold of 0.05 µg kg⁻¹. The results of measurements were expressed as average values of 3–5 initial ones. The results of different tests analyses were intercompared to determine their statistical magnitude of discrepancy basing on t-criterion by Student, the confidential probability being P=99% (at the significance point of α=0.01). Statistical processing was performed in accordance with standard methodology.

3. The results and their discussion

The concentration of B(a)P in the leaves of three hard wood types was studied on the territory of Irkutsk represented by a number of highways and yards (Fig.1). The hard wood trees grow at different distances from the highways. The results of mixed leaves tests showed the availability of B(a)P in them irrespective of their being washed free and not being washed free of silt. (Table 1).

Table 1. The concentration of benzo(a)pyrene in hard wood leaves growing on the territory of the town of Irkutsk³.

| Location and site of test (s.t.) | Benzo(a)pyrene mass concentration in hard wood leaves, µg kg⁻¹ |
|----------------------------------|---------------------------------------------------------------|
|                                  | birch | poplar | maple |
|                                  | not washed | washed | not washed | washed | not washed | washed |
| S.t. 1 Stanisl. yard             | 6 ± 2 | 4 ± 2 | 8 ± 3 | 5.0 ± 2.5 | 10 ± 4 | 3.4 ± 1.7 |
| S.t. 2 Yubileiny yard            | 10 ± 4 | 4 ± 2 | 9 ± 3 | 7 ± 3 | 12 ± 4 | 3.5 ± 1.7 |
| S.t. 3 Akademgor. yard           | 8 ± 3 | 4 ± 2 | - b | 5.0 ± 2.5 | 12 ± 4 | 6 ± 2 |
| S.t. 4 SEP dam                   | 7 ± 3 | 4 ± 2 | 3.5 ± 1.7 | 11 ± 4 | 7 ± 3 |
| S.t. 5 Yubilein                  | 10 ± 4 | 8 ± 2 | 8 ± 3 | 6 ± 2 | 38 ± 14 | 7 ± 3 |
| S.t. 6 Lermont. Str.             | 6 ± 2 | 62 ± 1 | 5 ± 3 | 3 ± 2 | 12 ± 4 | 4 ± 2 |
| 3 m from high way                | 12 ± 4 | - b | 22 ± 7 | 9 ± 3 | 10 ± 4 | 6 ± 3 |
| 5 m from high way                | 9 ± 3 | 4 ± 2 | 9 ± 3 | 9 ± 3 | 10 ± 4 | 4 ± 2 |
| S.t. 7 Baikal. Str., 5 m. from high way. | 12 ± 4 | 8 ± 3 | 8 ± 3 | 14 ± 5 | 22 ± 8 | 9 ± 3 |
| Tests, total number (n).         | 8.9 ± 2.3² | 4.8 ± 2.1² | 9.5 ± 4.7² | 6.7 ± 3.4² | 14 ± 9² | 5.2 ± 1.9² |
| Degree of Pollution⁴             | moderate³ | background³ | moderate³ | moderate³ | considerable³ | background³ |

³Notes.

²gap “-” – no information;

¹mean absolute ± standard deviation (SD);

⁴vegetation background level of 1–5 µg kg⁻¹ [19]. MPC (maximum permissible concentration value) is not available. Pollution is moderate (up to 10 µg kg⁻¹), considerable (11–12 µg kg⁻¹) and great (greater then 20 µg kg⁻¹).

Mass concentrations of cancer-causing factor varied in the range of 2–38 µg kg⁻¹ values of airdry leaves mass. In most tests (47 out of 59) the leaves are characterized as “moderately ” polluted with regard to B(a)P concentration, after that comes “considerably” polluted (9 tests) and then “greatly”
polluted (3 tests). The difference of results is mainly within the error of definitions, therefore they could be united in groups and compared with regard to mean concentrations basing on the 1st criterion by Student. Comparison of average B(a)P concentrations in the leaves of different hard wood tree groups unwashed and washed free from silt was equally valid for all types of trees and revealed a statistically significant difference, namely: a wash off with water considerably removes B(a)P from the plants. The intensity of the wash depends on a wood type and decreases in the line: maple (63%), birch (46%) and rough-bark poplar (30%), thus demonstrating different ability of leaves to keep the silt outside the leaves. It is evident that the poplar leaves adsorb the particles more intensively as they have adhesive, resinous coating.

In the washed off leaves, the concentrations of B(a)P decrease reaching the values close to the background ones (See Table 1), there being no statistically significant differences between the results obtained with regard to different species of plants observed. A conclusion can be made that there is a considerable concentration of B(a)P on the outer surface of leaves. Their species is of some importance for the phenomenon too, because a small accumulation of the substance is observed in the plant tissues that do not show any species specificity.

To determine the dependence of B(a)P accumulation by hard wood leaves on their distance from highways which means from the motor transport emissions into the atmosphere, a statistical processing of all vegetable test groups was carried out, leaves preparation (washed free and unwashed of the silt) and the species of the trees being not taken into consideration. It was found out (Table 2) that average concentrations of B(a)P have a clearly expressed tendency to decrease with a greater distance from highways and reach background concentrations. Inside the yards and in miniparks irrespective of a test plot location relatively a lateral river, the hard wood leaves under investigation contain a smaller amount of contaminating material, than the ones along active highways. However, the background level is not reached even in the yards as there is the difference of average concentrations of B(a)P which is statistically significant as (t_{calc.} = 4.28 > t_{table} (0.01; 33) = 2.81).

**Table 2. Benzo(a)pyrene accumulation in washed free and unwashed hard wood leaves, growing at different distances from highways.**

| Distance from highways | Average B(a)P concentration, µg·kg^{-1} (n – number of tests) |
|------------------------|---------------------------------------------------------------|
|                        | Birch, poplar and maple leaves (unwashed and washed) | Poplar leaves (washed) |
| 3 m from highways      | 13 ± 9^b (n=11) | 14^c (8–25, n=14) |
| 5 m from highways      | 8 ± 5^b (n=22) | 11^c (8–12, n=15) |
| 15-20 m from highways  | 6 ± 3^b (n=10) | 10^c (7–12, n=10) |
| Yards and public gardens | 7 ± 3^b (n=16) | 9^c (8–12, n=23) |
| Background territory for the birch and poplar | 3 ± 2^b (n=19) | 3^c (1–5, n=15) |

^aNotes.

^bmean absolute ± standard deviation (SD).

^caverage value (minimum – maximum).

In vegetable materials washed free of silt concentrations of B(a)P are close to background ones irrespective of the trees growing place. This does not allow to draw any reliable conclusions on the possibility of using plants as biomonitors of the atmosphere quality. That is why an additional analysis of the results was made engaging plant tissues washed free of silt as a means of studying poplar leaves being a very common type of green planting in Irkutsk. Their average and extreme concentrations of B(a)P are close to their “moderate” degree of vegetable pollution and correlate well with the results obtained for different species of plants (See Table 2.). Comparing results is indicative of a tendency to
a decreased accumulation of pollution in poplar leaves with increasing distances from highways, the inequality of B(a)P medium concentrations in poplar leaves growing in the yards is statistically not so much significant in comparison with roadside trees ($t_{\text{calc}} = 2.82 > t_{\text{table}} (0.01; 35) = 2.75$). At the same time, statistically more significant pollution of tree leaves from the yards is registered in comparison with a background level ($t_{\text{calc}} = 4.23 > t_{\text{table}} (0.01; 36) = 2.70$). Statistically significant differences between the B(a)P concentrations in poplar leaves washed free of silt and growing at different distances from highways allow to recommend this kind of a plant material as a biomonitoring one to assess the condition of the atmosphere and the plants in the urban environment in the warm season of the year. These indicators, however, are not characteristic for their high sensitivity and require large test cutting to arrange monitoring.

The results represented in Table 2 clearly indicate at the dependence of vegetable plant pollution on its remote location from highways as basic sources of atmosphere pollution. It should also be kept in mind that in the urban environment the yard territories being planted with trees and shrubs and closed from highways are considered to have the most favourable conditions for human activities.

The comparative analysis of B(a)P accumulation by hard wood leaves growing on the plots of different terraces (of the landscape) made it possible to mark the following features. On the plot located on the third terrace a significantly increased pollution has been marked. Increased concentrations have been registered on the fourth terrace with regard to unwashed leaves tests from the highways. This can be connected with the motortransport charge. In the yards similar tests contain close B(a)P concentrations. Washed hard wood leaves along the highways (not polluted outside) are characteristic for an increased concentration of B(a)P at the distance from a river flood-plain to the fourth terrace. The B(a)P distributions observed in the system of a “source – plant” are necessary to be correlated with peculiarities of emission diffusion.

4. Conclusion

The concentration of cancer-causing B(a)P was studied in the leaves of rough-bark poplar (Populus balsamifera L.), drooping birch (Betula pendula L.), sugar maple (Acer negundo L) in the urban environment of the town of Irkutsk, Irkutsk region with regard to landscape-transport exposure. It has been established that moderate (up to 10 µg kg⁻¹) and considerable (11–20 µg kg⁻¹) degrees of hard wood leaves pollution are predominant as concerns B(a)P. The level of a matter concentration is determined, first of all, by the conditions of test preparations, the greatest concentrations of B(a)P being found in the plant material the surface of which has not been washed free of silt. The amount of a “washable” matter depends on the kind of a plant and decreases according to the wood line: maple, birch and poplar. Therefore, plant tissue biomonitoring is recommended to identify the sources of emissions into the atmosphere in the cases the outer pollution has not been removed from the plants. In the plant materials, that have been washed free of pollution, the B(a)P concentrations are close to background ones (1–5 µg kg⁻¹) and do not depend on the kind of a plant or the place of its growing. Secondly, the degree of hard wood leaves pollution conditions the place of green plant growing. It means that the greater is the distance from highways, the smaller is the B(a)P concentration. This regularity is observed irrespective of the kind of a plant having a minimum level pollution of hard woodsgrowing in yards and public gardens. The result obtained allows to consider the motor transport to be the main source of plant polluting and the atmosphere which is interconnected with plants during the warm season.

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