Assessment of the Impact of Air Pollution on Plants in the City of Krasnoyarsk

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Abstract. The background state of the environment of urban areas is formed due to the combined effects of industrial and transport emissions, as well as as a result of their secondary interaction. The concentration of emissions depends on landscape, urban planning and weather conditions. The environmental background affects the changes in individual landscape elements. However, processes occur in separate points of the city that additionally form or disperse pollutants, as a result of which local situations develop at the micro-territorial level, which differ from the background state of the environment. In this case, the local situation may differ both in the positive and in the negative direction. More comfortable conditions develop in areas where planning decisions correspond to microclimatic and orographic situations, in large landscaped areas, near water bodies, etc. Local conditions that increase the level of environmental pollution are formed by situations that depend on territorial distribution, intensity of occurrence, time of occurrence and duration adverse effects. Therefore, when designing landscaping objects and choosing technology for planting care, it is necessary to take into account the conditions for their growth at the local level. At the same time, the assessment of phytoecological conditions should include landscape, urban, syn, and outecological aspects, which determine the growth and development of individual plants and the state of plantings as a whole [1].

1. Scientific significance
The city of Krasnoyarsk since 1934 has been the capital and one of the industrial centers of the Krasnoyarsk Territory, located on the banks of the Yenisei River. The formation of the Krasnoyarsk Territory in combination with the country's transport arteries through Krasnoyarsk gave a quick start to the development of industry in the city. In the first ten years, 33 new industrial enterprises were introduced in the city. During the Second World War, Krasnoyarsk deployed more than 80 evacuated industrial enterprises on its territory and in the region. In the 1950s Krasnoyarsk is becoming one of the largest industrial centers in the country. The whole world knew about the construction of the largest aluminum plant in Krasnoyarsk. Thus, in the second half of the twentieth century, Krasnoyarsk was on the rise of its economic development. [2]. In those years, the main issue was to get the maximum amount of products from factories under construction, and environmental issues were
resolved on a residual basis. The population of the city for decades lived in conditions of constant environmental pollution. After many years, some industrial enterprises were closed or reprofiled, which severely affected the socio-economic situation of the city's inhabitants, but had a beneficial effect on the quality of atmospheric air. However, the industrial giants of non-ferrous metallurgy, heat power engineering and a number of others are still continuing their activities. About 13 thousand one-, twostory private households located inside the city and equipped with domestic boiler houses, which also make an additional contribution to environmental pollution throughout the cold season, were officially taken into account.

A huge contribution to the pollution of the air basin of Krasnoyarsk is made by cars. The most dangerous fact is that harmful emissions from cars pollute the air directly in the area of human breathing. The number of private cars is increasing, and freight traffic is growing.

Statistical data on the presence and volume of pollutant emissions [3] indicate that 271 pollutants in the volume of gross emissions of about 175 thousand tons per year come from all stationary and mobile sources of pollution into the air.

There is a need to warn the population and authorities about the deteriorating environmental situation in a particular microdistrict in order to take timely measures to reduce pollution and implement environmental measures. One approach to assessing environmental pollution is the use of bio-indicators. In practice, bioindication methods make it possible to fix the presence and concentration of a pollutant in a natural component at a local level, evaluate the ability of pollutants to accumulate in organisms, and determine the limits of biological objects' stability from the degree of exposure to threatening factors. The presence of a substance does not necessarily mean that it can accumulate in biological objects and cause certain reactions, both positive and negative, leading to death. Anthropogenic pollution affects living organisms, including humans, in a variety of combinations. Their integral influence can only be assessed by the reaction of living organisms or entire communities.

Additional advantages of biological methods for monitoring environmental quality are relatively low cost, do not require preliminary analyzes of chemical compounds or physical effects, and make it possible to characterize the state of the environment over a long period of time [1, 4].

2. Objects and methods of research

Environmental pollution monitoring in the Krasnoyarsk Territory is carried out at the federal and regional levels [5].

According to the current principles, it is customary to monitor the levels of air pollution in Russian cities using stationary posts [6]. Stationary posts are small-sized buildings equipped with special gas analyzers, dust meters, etc. The number of stationary posts in the city is selected based on its size, climatic features, terrain and industrial enterprises. The automated post should be located in a well-ventilated area or in the area of the possible appearance of maximum concentrations of pollutants. Currently, 8 posts of the state and 9 posts of the regional observation network are functioning in the territory of the city of Krasnoyarsk and the surrounding areas. In addition to meteorological parameters (wind direction and speed, air temperature and humidity, atmospheric pressure), more than 21 pollutants are assessed for air pollution in Krasnoyarsk. The list of observed indicators at the posts of the observational network is presented in table 1.

In accordance with clause 2.4 of RD 52.04.186-89 [6] and GOST 17.2.3.01-86 [7], monitoring of the content of pollutants, which make the main contribution to air pollution, is made at stationary posts: suspended solids (PM and PM 2.5), sulfur dioxide (SO2), carbon monoxide (CO), nitric oxide and dioxide (NO and NO2).

The list of specific pollutants for observations is established on the basis of the population of the city, as well as the composition and nature of emissions from pollution sources in the city and meteorological conditions for the dispersion of impurities [6]. The pollutants emitted by the city enterprises are also determined, and the possibility of exceeding the maximum permissible concentrations of these substances is assessed. In addition to priority, the list of specific pollutants for
the city of Krasnoyarsk includes: formaldehyde [8], lead (Pb), benz(a)pyrene (C20H12) [9], hydrogen sulfide (H2S), ammonia (NH), aromatic hydrocarbons, hydrofluoride (FH), hydrochloride (HCl).

Table 1. The list of observed pollutants.

| Post number | Location                                      | List of pollutants                  |
|-------------|-----------------------------------------------|-------------------------------------|
| S1          | Krasnoyarsk, Minusinskaya st., 14 d           | SO2, CO, PM, NO, NO2, CH2O, C20H12, H2S, FH, HCl, NH3, aromatic hydrocarbons. |
| S2          | Krasnoyarsk, Surtikova st., 54 m              |                                     |
| S3          | Krasnoyarsk, Bykovskogo st., 4 d             |                                     |
| S4          | Krasnoyarsk, Matrosova st., 6d               |                                     |
| S5          | Krasnoyarsk, Kutuzova st., 92 g              |                                     |
| S6          | Krasnoyarsk, Chaykovskogo st., 7 d           |                                     |
| S7          | Krasnoyarsk, 26 Bakinskikh Komissarsov st., 26 d |                                     |
| S8          | Krasnoyarsk, Krasnomoskovskaya st., 32 d     |                                     |
| R1          | Krasnoyarsk, Gusarova st., 9 a               | CO, SO2, NO, NO2, H2S, NH3, PM 2.5  |
| R2          | Krasnoyarsk, Aviacyonnaaya st., 86           |                                     |
| R3          | Krasnoyarsk, Mote Zalki st., 4               |                                     |
| R4          | Krasnoyarsk, Solnechny blvd., 2             | CO, SO2, NO, NO2, H2S, NH3, PM 2.5, aromatic hydrocarbons, FH, HCl, poorly soluble fluorides, C20H12, Pb, CH2O. |
| R5          | Krasnoyarsk, Lvovskaya st., 50               |                                     |
| R6          | Krasnoyarsk, Pavlova st., 21/1              |                                     |
| R7          | Krasnoyarsk, 60 lat Oktyabrya st., 46        |                                     |
| R8          | Kubekovo, Novaya st., 6                      | CO, SO2, NO, NO2, PM 2.5            |
| R9          | Berezovka, Beregovaya st., 40                |                                     |

Stationary posts are conditionally divided into «urban background» (S1), «industrial» near enterprises and at the border of sanitary protection zones (S5, S6, S7, R2, R3, R4, R5, R8, R9), «road» near highways in areas with heavy traffic (S2) and «residential» (S3, S4, S8, R1, R6, R7) [10].

To characterize the level of atmospheric pollution of a given territory over a long period of time, the complex atmospheric pollution index (IZA5) is used. To calculate the index, the average concentrations of pollutants are used (five substances that make the main contribution to creating a high level of pollution), referred to the maximum permissible concentrations and reduced to the harmfulness of sulfur dioxide in accordance with the provisions of RD 52.04.667-2005 [11]. According to the IZA5 gradation, the level of pollution is considered «low» (0 < IZA5 ≤ 4), «increased» (5 ≤ IZA5 ≤ 6), «high» (7 ≤ IZA5 ≤ 13) and «very high» (14 ≤ IZA5) [11]. Most industrial cities of the Russian Federation have a «high» and «very high» level of air pollution.

According to the results of atmospheric air monitoring in 2018, the priority pollutants were: benz(a)pyrene, formaldehyde, ammonia, nitrogen dioxide, suspended solids. In 2018, the level of pollution in Krasnoyarsk was characterized as «very high» - the integrated index of air pollution was 21 units. In the city atmosphere in 2018, cases of exceeding hygiene standards for benz(a)pyrene, suspended solids (PM and PM 2.5), carbon monoxide, nitric oxide and dioxide, phenol, hydrofluoride, hydrochloride, formaldehyde, xylene, ethylbenzene and cumene. The highest values were in the cold season for benz(a)pyrene. The maximum was recorded in December. The warm period of the year was characterized by high values of repeatability of excesses: in July - 53.8%.

The issue of air quality is currently being considered mainly from the point of view of its influence on humans. In accordance with the federal law «On Environmental Protection» [12], the standards for permissible emissions and discharges for enterprises are determined in relation to pollutants by calculation on the basis of the standards for maximum permissible concentrations, taking into account the background state of the components of the environment. However, even with the observance of the norms of maximum permissible physical influences and concentrations, the trees around industrial enterprises degrade and die. This circumstance indicates a higher sensitivity of plants to many types of pollution [13] in comparison with humans. At the moment, the area of maximum permissible concentrations for green spaces has been little studied. To assess the effect of atmospheric pollution on the state of green spaces, maximum permissible concentrations for 12 pollutants — phytotoxic maximum allowable concentrations [14, 15] - have been developed. They have a similar
standardization structure, but their application is difficult due to the variety of plant species and their physiological differences (for example: herbaceous, shrubs, deciduous or coniferous trees, etc.), affecting the resistance of a species to various pollutants. The maximum permissible concentrations of pollutants in the atmospheric air of populated areas in relation to plants and humans are shown in Table 2, which shows that plants are less resistant to organic compounds [15 - 17]. Due to the fact that at stationary monitoring stations for atmospheric air pollution, changes in the concentration of hydrochloride are carried out, further calculations were carried out with respect to hydrochloride.

| Name of the pollutant | Hazard class | for humans maximum one-time (MAC<sub>mo</sub>) | for plants MAC<sub>mo</sub> | MAC<sub>da</sub> |
|-----------------------|--------------|-----------------------------------------------|--------------------------|---------------|
| SO<sub>2</sub>        | 3            | 0.5, 0.05                                     | 0.1, 0.05                |               |
| NO<sub>2</sub>        | 3            | 0.2, 0.04                                     | 0.09, 0.05               |               |
| NH<sub>3</sub>        | 4            | 0.2, 0.04                                     | 0.35, 0.17               |               |
| O<sub>3</sub>         | 1            | 0.16, 0.03                                    | 0.47, 0.24               |               |
| Hydrocarbons (gasoline) | 4      | 5.0, 1.50                                     | 0.65, 0.14               |               |
| CO                    | 4            | 5.0, 3.0                                      | 6.7, 3.3                 |               |
| C<sub>2</sub>H<sub>12</sub> | 1     | 0.000001                                      | 0.0002, 0.0001           |               |
| Benzene               | 2            | 0.3, 0.1                                      | 0.1, 0.05                |               |
| PM                    | 3            | 0.5, 0.15                                     | 0.2, 0.05                |               |
| H<sub>2</sub>S        | 2            | 0.008, -                                       | 0.008, 0.008             |               |
| CH<sub>2</sub>O       | 2            | 0.05, 0.01                                    | 0.02, 0.003              |               |
| FH                    | 2            | 0.02, 0.005                                    | -                     , 0.00166 |               |
| Cl                    | 2            | 0.1, 0.03                                     | -                     , 0.025 | 0.015 |
| HCl                   | 2            | 0.2, 0.1                                      | -                     , 0.025 | 0.015 |

Differences in the maximum allowable concentrations of pollutants for humans and plants can vary by tens of times. According to the results of the studies, it was found that the level of danger and the qualitative composition of pollutants for the population and plants also varies significantly. For humans, a series of toxicities from the most common impurities, starting with the most harmful, is as follows: Cl -> SO<sub>2</sub> -> NH<sub>3</sub> -> HCN -> H<sub>2</sub>S. For plants, the most dangerous are Cl, SO<sub>2</sub>, NO<sub>2</sub>, NH<sub>3</sub>, fluorides. Less dangerous are CO, H<sub>2</sub>S and hydrocarbons. Three-fold excess of the normative permissible air pollution for green spaces causes a decrease in photosynthesis, five-fold - a violation of plant morphogenesis and productivity, ten-fold - the death of sensitive species (conifers) and plant degradation [1, 18]. Based on the results of instrumental monitoring, an assessment of air pollution in the city of Krasnoyarsk was carried out for substances for which phytotoxic maximum permissible concentrations were established. Table 3 shows the atmospheric air characteristic of the city of Krasnoyarsk for 2018.

The average annual concentrations of relevant pollutants in the city of Krasnoyarsk are defined as the average values obtained from observations of the regional and state network of stationary posts. For substances, the average annual values of which did not exceed hygienic standards, the threshold value adopted for calculations is the average daily maximum permissible concentration. For example, for sulfur dioxide, the average annual concentration according to the state network of posts will be «less than 0.05 mg/m<sup>3</sup>», but 0.05 mg/m<sup>3</sup> is taken for calculations.
Table 3. Characteristics of atmospheric air in Krasnoyarsk in 2018.

| Name of the pollutant | The average annual concentration of pollutants according to the data, mg/m³: | The average annual concentration of pollutants in Krasnoyarsk, IZA, index based on MAC₆₅ |
|----------------------|-------------------------------------------------|-------------------------------------------------|
|                      | Regional posts | Federal posts | For human | For plants | For human | For plants |
| SO₂                  | 0.014          | ≤ 0.05        | ≤ 0.032   | ≤ 0.64     | ≤ 0.64    | ≤ 0.64     |
| NO₂                  | 0.049          | 0.036         | 0.043     | 1.06       | 0.85      | 1.06       |
| NH₃                  | 0.0084         | ≤ 0.04        | ≤ 0.0242  | ≤ 0.61     | ≤ 0.14    | ≤ 0.65     |
| CO                   | 0.65           | 1.2           | 0.93      | 0.31       | 0.28      | 0.37       |
| Бензол              | 0.0005         | ≤ 0.1         | ≤ 0.05    | ≤ 0.50     | ≤ 1.00    | ≤ 0.41     |
| PM                   | -              | 0.102         | 0.102     | 0.68       | 2.04      | 0.68       |
| H₂S                  | 0.0023         | 0.017         | 0.0023    | -          | 0.29      | -          |
| CH₂O                 | 0.0024         | ≤ 0.005       | ≤ 0.004   | ≤ 0.8      | ≤ 2.29    | ≤ 0.75     |
| HF                   | 0.0026         | ≤ 0.01        | ≤ 0.086   | ≤ 0.86     | ≤ 5.73    | ≤ 0.82     |
| HCl                  | 0.071          | ≤ 0.1         | ≤ 0.086   | ≤ 0.86     | ≤ 5.73    | ≤ 0.82     |
| C₂₀H₁₂, mkg/m³      | 0.0013         | 0.0065        | 0.0039    | 3.90       | 0.0039    | 7.70       |

Based on the results, the integrated index of atmospheric pollution for plants for five priority pollutants (hydrochloride, hydrofluoride, nitrogen dioxide, formaldehyde and suspended solids) as of 2018 is 27.66 units, which is 24% higher than this indicator for person. The obtained results complement the studies conducted by Avdeeva E.V. with co-authors in the period from 2006 to 2010. That period is characterized by a high content of nitrogen dioxide and suspended particles in the atmosphere of the city of Krasnoyarsk. However, in 2018, the concentrations of formaldehyde and hydrochloric acid were many times higher than the values obtained in the period 2006-2010. As mentioned earlier, formaldehyde sources can be exhaust gases from vehicles, industrial emissions, and photochemical processes leading to smog formation. 2018 is also indicative of a long period of adverse weather conditions, amounting to about one and a half months, which in combination with clear sunny weather can lead to additional formation of formaldehyde during photochemical reactions.

It is not possible to characterize such high values obtained with respect to hydrochloride due to the unavailability of information from industrial enterprises - potential sources of this pollutant.

After the calculations, the obtained IZA₅ values calculated in relation to the plants were compared with the IZA₅ values calculated in relation to the person taken from the state reports «On the State and Environmental Protection in the Krasnoyarsk Territory» [19 - 25]. The levels of the air pollution index for the period from 2006 to 2010 and 2018 are presented in Figure 1.

Figure 1. IZA₅ levels.

Based on the results obtained, we can conclude that it is necessary to use plants as an indicator of environmental degradation before pollutants begin to cause significant harm to human health.

Thus, the developed hygiene standards for the maximum permissible concentrations of pollutants in urban areas for the population cannot ensure the sustainable development of vegetation. To organize monitoring of environmental pollution using dendroindication methods, the development of maximum permissible concentrations for plants is required, which determine the magnitude of the allowable combined effect of all sources, and when observed, the stable functioning of natural ecological systems is maintained and biological diversity is preserved. The influence of technogenic impacts on
the state of urban ecosystems in general and its individual components must be evaluated by the totality of hygienic and biological indicators.

3. References

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