Analysis of the impact of economic activity on atmospheric air quality in Ulan-Ude

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Abstract. The growth of negative environmental impact requires increased attention to the processes of air protection. In recent years, significant imbalance of the biosphere has been clearly observed. This study proved a significant excess of negative environmental impact of Ulan-Ude in comparison with assimilation potential of the environment. Ulan-Ude, which is annually included in the list of the most polluted cities in Russia in terms of the level of atmospheric pollution, this problem is mainly due to the processes associated with the generation of electricity and motor transport. Very high concentrations of benzo[a]pyrene (hazard class 1), formaldehyde (hazard class 1) and particulate matter in Ulan-Ude contribute to an increase in the incidence of children and adults. High depreciation of environmental protection equipment, insufficient expenditures on atmospheric protection measures, and comparability of payments for normative and excessive pollution determine the inefficiency of the existing environmental policy.

1. Introduction

The city of Ulan-Ude since 2009 (2008, 2010-2012 was not included) is annually included in the Priority list of cities in Russia with a high level of air pollution. In 2016, from the 20 cities of the Priority List, 9 cities of the Baikal region were included in the list (the cities of Bratsk, Zima, Usoleye-Sibirskoe, Cheremkhovo, Shelekhov of the Irkutsk Region, the village of Selenginsk of the Republic of Buryatia, Chita, Petrovsk-Zabaykalsky of the Zabaikalsky region).

Atmospheric air pollution in cities and towns of the Baikal Natural Territory (BNT) is caused by anthropogenic activities, natural processes, forest fires, and transboundary transport of polluted air masses. The anthropogenic change in the air environment occurs due to emissions of pollutants as a result of industrial and other activities of enterprises, organizations and institutions (stationary and area sources), mobile vehicles (cars, rail and air transport), heating boilers and furnaces of the private residential sector.

The main factors for dispersion of harmful emissions are inversions, calms, fogs, wind conditions and vegetation, because they determine the air pollution of human settlements.

According to research of A S Mikheeva [1] the territory of the city of Ulan-Ude, as well as the entire territory of Buryatia, belongs to the territories with low possibilities of self-purification of the atmosphere. A quantitative assessment of factors favoring dispersion (the number of days with wind of ≥ 15 m/sec, the number of days with precipitation ≥ 5 mm) is significantly lower than the assessment of factors preventing the purification of the atmosphere (the number of days with fog, the number of days with calm, the number of days with relative humidity air 80%). The calculated values of the climate self-purification potential of the atmosphere as a whole for the territory of the republic...
are characterized as low, which depends primarily on the regional features of the natural environment, caused by the action of the Asian anticyclone, in which powerful temperature inversions form a retarding layer and impede the transfer of impurities.

The high reproductive capacity for atmospheric oxygen in the territory of Buryatia, determined by forest cover (2016 - 63.7%) eliminates the low self-purification capacity of atmospheric air, however, the residential level of Ulan-Ude is characterized by low reproduction of atmospheric oxygen [1].

Quantitative assessment of air quality is a priority for environmental management. A complex indicator characterizing the state of atmospheric pollution is the atmospheric pollution index (API), which is calculated from the values of average annual concentrations of pollutants and depends on the degree of danger of the impurity. The indicator characterizes the level of chronic air pollution. In accordance with the existing assessment methods, the level of pollution is considered to be elevated with API from 5 to 6, high (H) with API from 7 to 13 and very high (VH) with API equal to or greater than 14. In 2016, a very high value was observed. The index of atmospheric pollution in all studied cities determines high average annual concentrations of benzo[a]pyrene (except for the village of Selenginsk), formaldehyde (except for the cities of Ulan-Ude, Cheremkhovo, Petrovsk-Zabaykalsky), suspended solids (except for the city of Zima).

Table 1. Indices of air pollution in cities of the Baikal region*.

| Settlement                | 2008    | 2010    | 2016    | Priority Pollution Agent (2016)                          | Pollution activity             |
|---------------------------|---------|---------|---------|----------------------------------------------------------|--------------------------------|
| Ulan-Ude                  | VH (16.2)| H (12.0)| VH      | benzo[a]pyrene, suspended solids                          | Power generation               |
| Bratsk                    | VH      | VH      | VH      | benzo[a]pyrene, carbon disulfide, suspended solids, formaldehyde, nitrogen dioxide | Pulp and paper production      |
| Zima                      | VH      | VH      | VH      | benzo[a]pyrene, nitrogen dioxide, formaldehyde, hydrogen chloride, carbon monoxide | Chemical production            |
| Usolye-Siberskovye        | H       | H       | VH      | benzo[a]pyrene, formaldehyde, suspended solids, nitrogen dioxide, sulphur dioxide | Chemical production, power generation |
| Cheremkhovo               | H       | H       | VH      | benzo[a]pyrene, nitrogen dioxide, suspended solids, sulphur dioxide, carbon monoxide | Power generation               |
| Shelekhov                 | H       | H       | VH      | benzo[a]pyrene, suspended solids, formaldehyde, hydrogen fluoride | Aluminium production, power generation |
| Village of Selenginsk     | VH (16.9)| VH (16) | VH      | benzo[a]pyrene, suspended solids, formaldehyde, nitrogen dioxide | Pulp and paperboard production |
| Chita                     | VH      | VH      | VH      | benzo[a]pyrene, suspended solids, nitrogen dioxide, formaldehyde, phenol | Power generation               |
| Petrovsk-Zabaykalsky      | VH      | H       | VH      | benzo[a]pyrene, suspended solids, carbon monoxide, nitrogen dioxide, sulphur dioxide | Power generation, railway transport |

*Sources: [2-6].

Practically in all studied cities of the Baikal region the main type of activity that pollutes the atmospheric air is the production, transmission and distribution of electricity, gas, steam and hot water. In the Irkutsk Region, 31% of the electricity produced comes from coal-fired power plants, 69% from hydroelectric power plants. [7]. Analysis of the strategy for the development of the fuel and energy complex of the Irkutsk region until 2010–2015 and for the future up to 2030, showed that coal will remain the main type of fuel at thermal power plants in the Irkutsk Region. Currently, most thermal
power plants are operated outside the standard service life [8]. In Ulan-Ude, the moral and physical deterioration of the equipment of the Heat and Power Plant-1 and the Heat and Power Plant-2 is also very high [9].

2. Models and Methods

Constant monitoring of air pollution in the city of Ulan-Ude is carried out at 3 observation points of pollution (16, Babushkin Street; 74, Street of Revolution of 1905; 15, 50th October Anniversary Prospect). In the city of Ulan-Ude, the average annual concentrations of benzo[a]pyrene (hazard class 1), formaldehyde (hazard class 1), suspended solids (hazard class 3) are well above the norm (Table 2).

| Name of the pollutant | 2010 | 2012 | 2015 | 2016 |
|-----------------------|------|------|------|------|
| sulphur dioxide       | 0.1  | 0.1  | 0.20 | 0.2  |
| nitrogen dioxide      | 1.1  | 1.1  | 1.10 | 1.0  |
| nitrogen oxide        | 0.3  | 0.2  | 0.40 | 0.3  |
| benzo[a]pyrene        | 3.4  | 2.8  | 7.22 | 6.7  |
| formaldehyde          | 2.2  | 0.2  | 1.10 | 1.1  |
| suspended solids      | 1.3  | 1.7  | 1.80 | 1.8  |
| Phenol                | 0.8  | 0.9  | 0.30 | 0.5  |
| carbon monoxide       | 0.4  | 0.5  | 0.20 | 0.1  |

* Source: data from the Federal Service for Hydrometeorology and Environmental Monitoring of Russian Federation.

Long-term observations show that the maximum single concentrations of benzo[a]pyrene, nitric oxide, phenol, nitrogen dioxide exceed the maximum allowable concentrations in the winter months, suspended solids in the autumn and spring months (Table 3).

| Name of the pollutant | 2010 | 2012 | 2015 | 2016 |
|-----------------------|------|------|------|------|
| sulphur dioxide       | 0.3  | 0.1  | 0.20 | 0.20 |
| nitrogen dioxide      | 3.6  | 1.6  | 2.00 | 2.70 |
| nitrogen oxide        | 0.3  | 0.2  | 1.10 | 1.40 |
| benzo[a]pyrene        | 7.0  | 8.2  | 24.2 | 21.7 |
| formaldehyde          | 2.0  | 1.9  | 1.60 | 1.10 |
| suspended solids      | 3.4  | 3.8  | 4.60 | 3.80 |
| phenol                | 1.4  | 4.0  | 3.30 | 1.90 |
| carbon monoxide       | 1.4  | 2.2  | 2.60 | 1.40 |

* Source: data from the Federal Service for Hydrometeorology and Environmental Monitoring of Russian Federation.

Anthropogenic pollution factors that determine the atmospheric pollution in Ulan-Ude are emissions from stationary sources, from mobile sources, from residential buildings, a high level of environmental equipment wear.

The largest contribution to the atmosphere of the city of Ulan-Ude from stationary sources are 3 groups of pollutants - solids, sulphur dioxide, carbon monoxide, which in total amount to about 86-88%. During the years under consideration, the amount of pollutant emissions averages 30 thousand tons of pollutants (table 4). The most significant enterprises in terms of emissions of air pollution are: Heat and Power plant-1 of Ulan-Ude (the contribution of this company to the total emissions from stationary sources is more than 33%), Heat and Power plant-2 of Ulan-Ude (19%), Ulan-Ude energy complex (heating boilers 17.5% of the energy complex), Ulan-Ude Aviation Plant Open Joint-Stock Company (over 5%), Ulan-Udealmost Joint-Stock Company (4.4%), Ulan-Ude Locomotive Car Repair Plant (2.1%).
Table 4 - Volumes of emissions of pollutants into the atmosphere of the city of Ulan-Ude

| Name of pollutant       | 2003        | 2010        | 2017        |
|-------------------------|-------------|-------------|-------------|
|                         | Thousand tons | %           | Thousand tons | %           | Thousand tons | %           |
| solids                  | 11.500      | 42.0        | 14.500      | 45.1        | 10.600        | 36.7        |
| sulphur dioxide         | 6.100       | 22.3        | 7.600       | 23.6        | 7.500         | 26.0        |
| carbon monoxide         | 5.800       | 21.2        | 6.200       | 19.3        | 6.800         | 23.6        |
| nitrogen oxides         | 3.400       | 12.4        | 3.000       | 9.4         | 3.200         | 11.1        |
| hydrocarbons            | 0.010       | 0.0         | 0.200       | 0.5         | 0.200         | 0.8         |
| volatile organic compounds | 0.600     | 2.2         | 0.600       | 2.0         | 0.500         | 1.7         |
| other gaseous and liquid | -          | -           | 0.025       | 0.1         | 0.017         | 0.1         |
| Total                   | 27.400      | 100.0       | 32.000      | 100.0       | 29.000        | 100.0       |

Sources: [10, 11].

Autonomous sources of heat supply (about 45 thousand houses) [12] make a significant contribution to air pollution in Ulan-Ude, while in 77.7% of cases furnaces are used and in 22.3% boilers [13]. As fuel, 81.9% of autonomous sources use firewood, 17.4% coal, 0.7% gas, liquid fuel, fuel briquettes and electrical heating.

Automobile transport makes a significant contribution to pollutant emissions. According to the Office of the Road Safety of the Republic of Buryatia, the number of registered vehicles in Ulan-Ude was 112,901, including cars – 93,582 (83%), trucks – 9,826 (9%), buses – 9,493 (8%). In the structure of pollutant emissions from mobile sources, the largest share is carbon monoxide (81.5%) (Table 5). To determine the volume of emissions and the share of pollutants, the Methodology for determining motor vehicle emissions was used to conduct summary calculations of urban air pollution [14].

Table 5 - Emissions of pollutants from mobile sources in Ulan-Ude

| Name of pollutant       | tons/year | %     |
|-------------------------|-----------|-------|
| carbon monoxide         | 23,286.7  | 81.50 |
| nitrogen dioxide        | 2,514.8   | 8.80  |
| carbon monoxide         | 2,419.4   | 8.50  |
| soot                    | 51.9      | 0.20  |
| sulphur oxide           | 260.8     | 0.90  |
| formaldehyde            | 41.2      | 0.10  |
| lead compounds          | 12.5      | 0.04  |
| benzo[a]pyrene          | 0.0022    | 0.00  |
| Total                   | 28,587.3  | 100.0 |

Source: authors' calculations.

The main contribution to the total intensity of the traffic flow is made by cars (on average, 77%). About 21% of the total traffic volume are trucks, of which 11% are diesel trucks. About 2% of the total traffic is contributed by buses, of which 41% are diesel buses [13]. According to the data, the highest traffic intensity is observed on the streets of Babushkina (5418 vehicles / hour), Borsoeva (4659 vehicles / hour), Ivolginskaya (4263 vehicles / hour). The number of mobile sources is growing annually, so the emissions from cars will increase annually.

3. Results and Discussion

The natural potential for atmospheric air is strictly limited, and the scale of the anthropogenic impact of the city of Ulan-Ude increases annually. Our study does not take into account emissions from autonomous sources of heating, rail transport, boilers that do not have permits for emissions, so the total pollutant emissions can be much higher. To compare the production and natural potentials of the territory of the city of Ulan-Ude, we conducted a comparative analysis of production intensity (total damage caused to natural objects and resources, the state of the environment and public health by construction and operation of economic facilities, their waste and products) and ecological technical...
capacity (indicator characterizing the maximum technogenic load that a set of recipients and environmental systems can withstand and endure over a long period system without violation of their structural and functional properties) according to the method T A Akimova and V V Haskin [15] (Table 6).

**Table 6.** Comparative analysis of anthropogenic load and ecological technological intensity of the territory of the city of Ulan-Ude.

| Indicators                                                                 | Value                |
|---------------------------------------------------------------------------|----------------------|
| Emissions of the most common substances from stationary sources, tons / year | 28,610.00            |
| Emissions of the most common substances from mobile sources, tons / year   | 28,587.30            |
| Volume of solid household waste, t / year                                 | 7,547,256.00         |
| Volume of pollutant discharge, tons / year                                | 25,576.90            |
| Accumulation of solid waste and air pollutants, conventional tons / year   | 7,630,030.20         |
| Ecological air capacity, conventional tons / year                         | 13,677,006,645.90    |
| Ecological water capacity, conventional tons / year                       | 114,277,315,968.00   |
| Ecological soil capacity, conventional tons / year                        | 3.80                 |
| Assessment of the ecological technical capacity of the territory, conventional tons / year | 1,458,768.60 |
| The ratio of anthropogenic load to the ecological technical capacity, times | 5.24                 |

*Source: [15, 16, authors' calculations].

**Table 7 - Expenses for protection of atmospheric air and payment for its pollution.**

| Indicators                                                                 | 2013     | % of total environmental protection costs / pollution charges | 2016     | % of total environmental protection costs / pollution charges |
|---------------------------------------------------------------------------|----------|-------------------------------------------------------------|----------|-------------------------------------------------------------|
|                                                                           | thousand roubles |                                     | thousand roubles |                                     |
| Current costs for the protection of atmospheric air                       |          |                                                      |          |                                                      |
| The Republic of Buryatia                                                 218,350  | 25.8                                              | 130,803   | 18.7                                                      |
| Ulan-Ude                                                                  35,508    | 12.9                                              | 38,100    | 15.0                                                      |
| Cost of the overhaul of basic production assets for air protection        |          |                                                      |          |                                                      |
| The Republic of Buryatia                                                 56,110    | 53.3                                             | 15,425    | 56.7                                                      |
| Ulan-Ude                                                                  22,117    | 64.8                                             | 2,378     | 22.8                                                      |
| Payment for permissible emissions of pollutants into the air            |          |                                                      |          |                                                      |
| The Republic of Buryatia                                                 26,112    | no data                                         | 19,378    | 50.7                                                      |
| Ulan-Ude                                                                  7,771     | no data                                         | 4,207     | no data                                                    |
| Payment for excess emissions of pollutants into the air                  |          |                                                      |          |                                                      |
| The Republic of Buryatia                                                 6,072    | 41.3                                              | 5,753     | no data                                                    |
| Ulan-Ude                                                                  2,523     | 30.9                                              | 3,092     | no data                                                    |

*Source: data of State Statistics of the Republic of Buryatia.

The calculation results prove that the anthropogenic load of the city of Ulan-Ude is significant and is more than 5 times greater than the assimilation potential to anthropogenic impact. Under these conditions, a priority should be to reduce the anthropogenic load on the territory in excess of the assimilation potential and to establish such values of pollution charges at which environmental protection costs are effective.

The analysis of the costs of environmental objectives, including the atmospheric protection measures of industrial enterprises of the Republic of Buryatia, presents considerable difficulties, since
these costs are usually taken into account as part of the total costs of the technological process or production. The level of capital investments and operating costs varies depending on the characteristics of the technology, the volume of gases being cleaned, their physical-chemical parameters, as well as the degree of wear and tear of the main production assets for environmental protection (Table 7).

A significant proportion of the cost of capital repairs of fixed assets for the protection of atmospheric air in the total amount of repair costs due to the high level of wear of this type of funds (55-60%). Comparability of payments for regulatory and excess pollution in the city of Ulan-Ude means that the power industry enterprises, as the main air pollutants, do not seek to reduce the over-limit air pollution. Paying a fee for excess emissions from profits, they do not invest in their own environmental measures. One of the ways to improve environmental policy should be to improve the system of payments for environmental pollution.

4. Conclusion
Analysis of air pollution in Ulan-Ude showed that a very high level of pollution is due to both natural and anthropogenic factors. High values of average annual concentrations of pollutants, as well as the authors’ calculations showed a significant excess of anthropogenic load over the natural self-cleaning potential of the territory of Ulan-Ude. The main directions of the city environmental policy should be the improvement of the environmental monitoring system of Ulan-Ude in terms of ensuring control over compliance with state environmental quality standards; assistance in the development of new requirements for territorial planning schemes; an inventory of the technological state of the basic production assets for atmospheric protection purposes; creating effective incentives for enterprises to reduce emissions into the atmosphere using a system of summary calculations of pollution; consideration of the possibility of creating a target environmental fund for the city of Ulan-Ude due to the redistribution of a part of non-tax payments to constituent entities of the Russian Federation; facilitating the creation of model geportals for the exchange of ecological, spatial, thematic data for the purposes of operational management and reducing the risks of extreme air pollution.

References
[1] Mikheeva A S 2012 Air pollution, in: Anthropogenic transformation of natural systems and socio-economic consequences in the Selenga river basin (Ulan-Ude: Buryat State University Press) pp 124-33
[2] State report On the state and environmental protection of the Russian Federation in 2016-2017 (Moscow: Ministry of Environment of Russia; NIA-Nature) p 760
[3] State report On the state and protection of the environment of the Irkutsk region in 2016-2017 (Irkutsk: Megaprint LLC) p 274
[4] State report On the state and environmental protection of the Republic of Buryatia in 2016-2017 (Ulan-Ude) p 232
[5] Report On the environmental situation in the Trans-Baikal Territory in 2016-2017 p 213
[6] Belozertseva I A and Khavina L A 2012 Environmental pollution in the area affected by IrkAZ and the health of the population of Shelekhov Siberian Medical Journal 110 (3) (Irkutsk: Irkutsk State Medical University) 122-4
[7] Solomin S V 2015 The forecast for the development of the electric power industry in the Irkutsk region until 2050 Proc. of the 27th All-Russian Scientific and Practical Conf. pp 41-4
[8] Sokolov A D, Takaishvili L N and Muzychuk S 2017 Yu Coal in the fuel and energy balance of the Irkutsk region Bulletin of the Irkutsk State Technical University 21, 12 (131) (Irkutsk: Irkutsk National Research Technical University) 185-94
[9] Tyskineeva I E 2017 Development of a method to reduce the negative impact of energy complexes on the environment and the rationale for the application of fluidized bed technology (Ulan-Ude)
[10] Statistical collection 01-01-18 Socio-economic situation of the cities of Buryatia 2008 (Ulan-Ude: Buryatstat) p 108
[11] Statistical collection 06-07-08 Environmental protection in the Republic of Buryatia 2017 (Ulan-Ude) p 53
[12] Causes of air pollution Ulan-Ude (Access mode: http://www.ulan-ude-eg.ru/admin-goroda/125076/?sphrase_id=1683420)
[13] Citywide summary volume Atmospheric protection and maximum permissible emissions (MPE) of the city of Ulan-Ude 2013 (St. Petersburg) p 481
[14] Order of the State Committee on Ecology of Russia 1999 Methodology for determining motor vehicle emissions for a summary calculation of urban air pollution (Moscow: State Committee of the Russian Federation on Environmental Protection)
[15] Akimova T A and Haskin V V 1994 Basics of eco-development (Moscow: Publishing House Ros. econ Acad) p 312
[16] Mikheeva A S and Ayusheeva S N 2017 Economic instruments for justifying environmental investments (FSBEI HE REU them. G V Plekhanov) p 192