Transboundary air pollution and its effects on vegetation

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Abstract. Currently, transboundary air pollution is one of the main factors of the negative impact of human activities on the environment. Protection of the atmosphere includes a set of technical and administrative measures directly or indirectly aimed at stopping or reducing the increasing pollution of the atmosphere, which is a consequence of industrial development. The effect of smoke and gas emissions is observed over large areas and manifests itself in various ways. The best indicator reflecting this effect is vegetation, which serves as a sensitive reagent for changing environmental conditions. The regulation of the influence of industrial facilities belonging to one administrative-territorial unit on the state of the environment of other regions is one of the most important aspects of environmental protection at the federal level and international cooperation in the field of ecology and environmental protection.

1. Introduction

The nature and size of atmospheric pollution is determined by the amount of pollutant emissions and the degree of their dispersion in the atmosphere due to the general meteorological situation and the type of underlying surface [1].

Admixture into the atmosphere is transported by air currents and falls on the underlying surface as a result of dry sedimentation and leaching by precipitation. However, many impurities enter into chemical interactions, which leads to negative consequences, since initially environmentally friendly substances can become dangerous forms or provoke the formation of harmful substances. Often gaseous impurities are converted into aerosols, whose duration in the atmosphere is determined mainly by the size of the particles [2].

The extent of the spread of pollutants from their emission sources is determined by the "lifetime" of impurities in the atmosphere.

The most common atmospheric pollutants include sulfur and nitrogen compounds, persistent and volatile organics, and dust containing heavy metals along with macro-components. Life expectancy in the atmosphere of these compounds ranges from several hours to several months. During this time, the impurity entering the atmosphere has time to travel over huge distances from the source of emission reaching thousands of kilometers. At the same time, even territories that do not have their own emission sources are polluted. Where they exist, the situation is getting worse. [3].
Therefore, it is extremely important to take these processes into account when designing new industrial enterprises.

2. Materials and methods
Based on the results of regional studies of aerotechnogenic environmental pollution using the example of the Orenburg region, we carried out a generalized analysis of the characteristics of transboundary air pollution and its impact on vegetation cover.

3. Discussion
Unlike anthropogenic systems, the atmosphere has no national borders. Therefore, the concept of transboundary transport was formulated, during which harmful substances emitted by the sources of one state fall on the territory of other states, having an adverse effect on humans, flora and fauna. The damage caused can reach hundreds of millions of dollars [4].

Considering this, in 1977 European countries launched the Joint Observation and Evaluation Program for the Distribution of Air Pollutants (EMEP) on the basis of the United Nations Economic Commission for Europe and with the support of the World Meteorological Organization. In 1983, the International Convention on Transboundary Air Pollution entered into force, under which European countries signed a number of Protocols on reducing emissions of pollutants into the atmosphere.

One of its main tasks was to create a strategy for the targeted reduction of emissions of pollutants into the atmosphere, taking into account the environmental and economic characteristics of European countries [3].

Annual calculations of transboundary fluxes of major pollutants for the entire European continent were entrusted to two major centers specially established under the Convention – «the West» Meteorological Synthesizing Center in Norway (MSC-W) and "the Vostok" Meteorological Synthesizing Center in Russia (MSC-V). The models developed in them make it possible to perform routine calculations of deposition of sulfur, oxidized and reduced nitrogen, heavy metals, and volatile organic matter for a selected area that captures the whole of Europe and part of Greenland (this is the so-called EMEP grid). The size of a standard grid cell is 50 km at a latitude of 60º.

The data obtained at these Centers are official and are considered by the Parties to the Convention, including Russia, as the basis for mutual reductions in pollutant emissions to the atmosphere.

Calculations made for Europe showed that with the present level of anthropogenic emissions, all European countries, including the circumpolar territories, are subject to varying degrees to atmospheric pollution. Thus, solving the problem of the transboundary transfer of pollutants is an urgent task for the environmental safety of not only individual states, but also of the whole of Europe [5-7].

From here it becomes obvious the importance of choosing a specific air protection strategy in a given state, which allows you to start developing a target level for reducing the pollution of a territory, where the cost of reducing emissions is not so great, and the effect of such a reduction is already acceptable from a practical point of view. This strategy includes creating a balance of pollutant deposition in specific regions, determining ecosystem-critical values of this fallout, and calculating economically and environmentally acceptable emission reductions relative to various sources [1,8,9].

The share of industry in the Russian Federation accounts for more than 80% of the volume of pollutants entering the air from all of the stationary sources counted (Table 1). At the same time, the share of the fuel and energy complex (FEC) accounts for almost 50% of the emissions of harmful substances into the atmosphere.

The negative impact of each individual sub-industry, which is a part of the FEC, has its own characteristics, which determine the specifics and nature of this impact. In the production of electricity and heat at TPPs of Russia, various types of organic fuel are used, and the composition of emissions from their combustion depends both on their component composition and on the combustion technology. When burning solid fuel, emission will inevitably contain solid particles, moreover, saturated with heavy toxic metals. The second inevitable component of emissions from the combustion
of solid and liquid fuels is sulfur oxides, since the fuel desulfurization technologies introduced in Russia are not yet sufficiently advanced [5,7]. On the other hand, in the emissions resulting from the combustion of natural gas, particulate matter and sulfur oxides are practically absent. The only component that is contained in emissions in comparable quantities, regardless of the type of fuel, is nitrogen oxides. Thus, from the point of view of the level of negative impact on the environment, it is preferable to extract and use natural gas for energy (Table 2).

In recent years, natural gas has become increasingly important as an energy carrier for the production of electrical and thermal energy both in Russia and in other countries. This is due, primarily, to the fact that the technologies of its extraction are environmentally friendly in nature and many harmful pollutants that are characteristic of, for example, combustion products of coal and mazut are absent in the products of its combustion. The gas industry is in 7th place in terms of emissions of pollutants into the air [2].

Table 1. Dynamics of emissions of pollutants into the air from stationary sources, kt

| Year | Russian federation | Industry | Power industry | Non-ferrous metallurgy | Oil industry | Ferrous metallurgy | Coal industry | Oil refining industry | Gas industry | Construction industry of materials | Chemical and petrochemical industry | Mechanical engineering and metalworking | Wood and pulp and paper industry | Food industry | Light industry |
|------|-------------------|----------|----------------|-----------------------|-------------|-------------------|-------------|----------------------|------------|----------------------------------|-----------------------------------|--------------------------------|-------------------------------|----------------|--------------|
| 1995 | 21269,6           | 18140,4  | 5017,7         | 3693,2                | 1409,1      | 2735,3            | 626,5       | 908,6                 | 707,7      | 674,2                           | 488,4                              | 725,6                           | 522,2                         | 300,3         | 74,2         |
| 1996 | 20274,1           | 16661,0  | 4748,5         | 3598,1                | 1309,7      | 2535,5            | 595,8       | 849,9                 | 541,8      | 528,0                           | 413,2                              | 602,5                           | 434,3                         | 250,2         | 64,4         |
| 1997 | 19332,9           | 15852,1  | 4427,7         | 3621,7                | 1325,1      | 2379,5            | 535,3       | 819,3                 | 451,1      | 467,9                           | 415,4                              | 543,3                           | 383,5                         | 224,4         | 56,0         |
| 1998 | 18661,8           | 14949,8  | 4345,7         | 3291,8                | 1385,0      | 2188,9            | 545,3       | 769,8                 | 428,5      | 467,9                           | 388,0                              | 460,1                           | 351,9                         | 198,0         | 50,1         |
| 1999 | 18539,7           | 14704,4  | 3935,5         | 3111,8                | 1376,2      | 2188,9            | 540,3       | 747,9                 | 456,3      | 416,9                           | 414,9                              | 454,1                           | 367,3                         | 198,2         | 50,6         |
| 2000 | 18819,8           | 15221,8  | 3857,3         | 3211,8                | 1329,0      | 2329,6            | 560,0       | 735,9                 | 501,0      | 440,7                           | 427,4                              | 433,2                           | 378,9                         | 181,8         | 45,4         |
| 2001 | 19123,6           | 15491,6  | 3655,8         | 3476,9                | 1619,0      | 2396,0            | 604,3       | 679,2                 | 475,8      | 440,7                           | 437,4                              | 432,7                           | 371,7                         | 168,4         | 43,6         |
| 2002 | 19481,2           | 15842,0  | 3352,7         | 3405,0                | 2119,7      | 2268,3            | 786,4       | 620,8                 | 536,9      | 455,0                           | 428,0                              | 370,1                           | 332,2                         | 162,9         | 41,2         |

Table 2. Specific emissions of pollutants from the combustion of various types of fossil fuels (kg / ton)

| Fuel                  | Particulate matter | Hydrocarbons | NOx | SOx |
|-----------------------|--------------------|--------------|-----|-----|
| Natural gas           | 0.05 - 0.2         | 0.03 - 0.3   | 5 - 20 | 0.01 - 0.02 | 1.5 - 6  |
| Motor fuel            | 2 - 8              | 10 - 40      | 15 - 60 | 3 - 30 |
| Mazut                 | 2 - 4              | 0.17 - 1.5   | 5 - 20 | 10 - 90 | 0.3 - 3  |
| Coal                  | 1 - 100            | 0.1 - 1.2    | 5 - 20 | 10 - 90 | 0.3 - 3  |
| Oil Recycled Fuel     | 0.3 - 3            | 0.3 - 3      | 0.1 - 0.4 | 0.3 - 3 |
In recent years, natural gas has become increasingly important as an energy carrier for the production of electrical and thermal energy both in Russia and in other countries. This is due, primarily, to the fact that the technologies of its extraction are environmentally friendly in nature and many harmful pollutants that are characteristic of, for example, combustion products of coal and mazut are absent in the products of its combustion. The gas industry is in 7th place in terms of emissions of pollutants into the air [2].

The preference of gas as a fossil organic fuel is also supported by the fact that specific emissions from gas extraction not only decrease every year, but they are also lower in absolute value than in other sub-sectors [4].

However, the gas industry objects emit a sufficiently large amount of nitrogen oxides, whose lifetime in the atmosphere reaches several days. During this time, they are transported over immense distances from the sources of their release and fall to the underlying surface, contributing to acidification of soils and water bodies. Therefore, there is a need to assess the impact of designed and existing facilities in the context of long-range transport of pollutants.

Possible adverse changes in vegetation cover. Under natural undisturbed conditions, vegetation cover and individual communities exist in a steady state. Communities deduced from the stationary state as a result of various external perturbations (disturbances) are restored to their original state within 150–200 years [10,11].

The main indicators of the state of vegetation cover are indicators of the state of individual components of plant communities, ranging from the most sensitive to pollution and other environmental changes (epiphytic lichen cover, moss cover) and ending with the most stable - cereals. At the same time, one of the main features that determine both the nature and rate of change is the initial degree of disturbance of communities as a result of external disturbances or the prescription of the latter external disturbance.

In the areas of local exposure to dust and gas emissions, substances can be present in the form of gases, acids, alkalis, salts, and solids that are poorly soluble, enriched with elements - toxicants. The impact of the solid component of dust and gas emissions will lead to a deterioration of the vital state of woody plants, which will manifest itself in a violation of material metabolism (deposition of calcium salts in the wood), premature aging, slower growth and development, morphological changes (growth, fascia). In herbaceous plant species, there will be both a worsening of the living state (calcefob) and improvement (calcephil). Abnormality is detected on the indicators of their morphology and productivity. Relatively sensitive mosses.

First of all, significant changes will affect the species composition of lower plants (fungi, epiphytic lichens), grass-shrub and partly shrub tiers in the forests and the structure of grass stand on the meadows. For forests (coniferous and small-leaved), a generally negative transformation is characteristic: a decrease in the vital status of tree species. In pine - decrease in the content of chlorophyll in the needles, especially in the spring - early summer period. Loss of lower plants from species composition (useful species of mushrooms - calcefobic: present, boletus, aspen, chanterelles), forming mycorhiza with roots of arboreal trees (common pine, hanging birch, aspen), which adversely affects the vital state of these species. Deterioration in the life of shrubs in the undergrowth — reduction in yield, taste, and deformation of fruits in certain species (black currant, cinnamon rose). Increased incidence of morphological anomalies and the incidence of certain plant species (tissue overgrowth - tumors on aspen branches, blackberry fruit creeper; «witches broom» on birch trees; fascia in some species of herbaceous plants). In the grass and grass-shrub tiers - loss of calcefob shrubs and grasses (blueberries, lingonberries, ozhiki hairy, one-year-old moons) and an increase in the growth of calcephils, especially species of legumes, orchids, cereals. Reduction in litter mass as a result of acceleration of its decomposition [3].

Significant negative transformation of highland bogs, characterized by almost complete changes in the species composition of vegetation - loss of cranberries and sphagnum mosses-calcefob, reduced abundance of a number of mosses with a relatively narrow ecological amplitude and increased abundance of species of mosses that withstand alkalization of soil solutions. In general, the role of
mosses and their species diversity was reduced in the cover of these swamps, and the role of sedges and forbs was increased [12].

The impact of the gaseous component of the smoke and gas emissions on vegetation cover has been observed for many tens of kilometers from the source. In the zone of extreme impact, there is a complete loss of species of trees from the community and replacing them with the shrub form of these same species, as well as the species of real shrubs (bush alder, goat willow).

In the ground cover in conditions of exposure to smoke and gas emissions, a complete restructuring in the community structure is possible. The most sensitive species (dwarf shrubs, green mosses) will replace low-value grass species (Siberian hogweed, creeping couch grass, pizhmol list wormwood, and large tail sedge). Moss cover will be fragmented and highly saturated with dust particles [13,14,3].

The degree of influence of smoke and gas emissions on plant organisms depends on such factors as: constancy of wind, air humidity, amount of pollutant emitted, particle size of aerosols, height of pipes and production technology.

The atmosphere other than sulfur dioxide is polluted by a large number of other substances, namely, zinc, lead, sulfur, copper, iron. These substances enhance the effect of sulfur dioxide, and the soil in the immediate vicinity of the source of exposure is more polluted by heavy metal salts. The components of smoke, heavy metals, in the largest quantities fall at a distance: lead and arsenic 1-3 km, zinc 1-5 km, copper 1-4 km [15]. Heavy metals are the most toxic among the chemical elements, an increase in their content in the soil always negatively affects the condition of the plants. Wild plants are more resistant to heavy metals. The highest content of heavy metals in cultivated plants is noted in the growth phase of plants, in the budding phase it decreases.

Thus, plants are subject to aggression from smoke and gas emissions not only in the aboveground part, but also the entire underground part is forced to assimilate from the soil excess trace elements and other compounds, which causes various deviations from the norm in the field of growth and development, appearance and physiological processes, and the chemistry of plants. [16].

The action of smoke and gas emissions causes the appearance of specific damage to plants, changes the appearance of the plant [15]. External damage can be of a different nature: a change in the color of the leaves, the appearance of a point, the mummification of part of the leaves, the reduction of the lamina, falling leaves, underdevelopment of shoots, buds, seeds, the complete death of the plant.

Conifers less gas resistant than hardwood. Among conifers, spruce is the least resistant to gas, and pine and larch are more resistant. Pine is more sensitive to the content of sulfur dioxide in the air, but it has a wide range of endurance [14,3,16,17].

Gas-resistant hardwoods include such species as birch, alder, elm, poplar. The most stable are: black alder, mountain ash and lilac. Medium-resistant hardwood: oak, elm and bird cherry. [13].

With respect to sulfur dioxide gas from grassy plants, clover and cereals are particularly sensitive; from decorative - sweet peas, primroses. High sensitivity of some fungi is noted.

It follows from the above data that the number of species does not always reflect the effect of smoke and gas emissions on vegetation, but the change in the qualitative composition of the steppe communities is quite obvious. [16].

The presence of methane and sulfur dioxide in the smoke-gas emissions causes the displacement of all phenological phases of plants and the weakening of the fruiting. These deviations are particularly prominent in the fall. In a number of plants, the growing season can be significantly shortened [12,18,19].

Epiphytic lichens have a broad spectrum of sensitivity to various changes in the environment and in particular types and kinds of air pollution. Under the conditions of exposure to smoke and gas emissions, a sharp reduction in the species diversity of epiphytes should be expected with a simultaneous increase in the number of eurytopic forms and species developing artificial substrates. Increased anthropogenic load will inevitably entail a change in the morphology of epiphytes. It is possible to increase the number of affected thalli, the appearance of thalli with low vitality and the following pathological changes: significant changes in the typical color of thalli, the shape and size of thalli. The reproductive potential of species may vary in different ways (the degree of development of.
media may decrease or increase). The area of damage to thalli in lichens is more dependent on the degree of impact of the source of pollution and the distance from it than on the age of thalli. With the help of indicator species, it is possible to conditionally identify the most clean and polluted areas of the territories. Conventionally, because the distribution of many species is associated with the spread of the substrate, and not with pollution.

4. Conclusion
As a result of transboundary atmospheric pollution on the vegetation cover, its species diversity decreases, the structure of plant communities is simplified, their zonal specificity is erased, resistance is reduced, and the active distribution of eurytopic, polyzonal vascular plants and bryophytes. The effect of smoke and gas emissions is observed over large areas and manifests itself in various ways. The best indicator reflecting this effect will be vegetation being a sensitive reagent for changing environmental conditions.

The degree of influence of smoke and gas emissions on plant organisms depends on such factors as: constancy of wind, air humidity, amount of pollutant emitted, particle size of aerosols, features of industrial production technology of the impact source. [20].

The acuteness of the problem of transboundary pollution and its impact on biological environments, in particular on vegetation cover, is that today Russia urgently needs an effective mechanism for managing industrial emissions, taking into account the ecological and economic conditions of the regions, and this mechanism should be implemented most effectively at the regional level. However, the presence of transboundary and interregional flows of pollutants in the atmosphere does not allow in many cases to significantly improve the environmental situation in a particular region. At the same time, the regulation of the influence of industrial facilities belonging to one administrative and territorial unit on the state of the environment of other regions is one of the most important aspects of environmental activities at the federal level, which is reflected in the Decree of the Government of the Russian Federation №777. It establishes that facilities subject to transboundary environmental pollution and having a negative impact on the environment within the territories of two or more constituent entities of the Russian Federation are subject to federal state environmental control.

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