

## Effect of Atmospheric Pollution on the Ecosystems of the Neryungri Fuel and Energy Complex (Yakutia)

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### Abstract

Atmospheric pollution of ecosystems in the region of the Neryungri fuel and energy complex (NFEC) was considered. Mathematical modeling of the processes of aerosol transport of dust, SO<sub>2</sub>, NO<sub>2</sub> was carried out by means of the formulation of the direct and inverse problems. An adequate model, in which the regions with different degree of atmospheric pollution were distinguished, was chosen on the basis of comparing the calculated dust content of the snow cover with the data experimentally measured for 22 sites. A correlation analysis of changes in the chemical composition of the upper horizons of top-soil and larch tissues (*Larix cajanderi* Mayr.) depending on the degree of atmospheric dust content was carried out. It was revealed that the concentrations of heavy metals (Fe, V, Ni, Cu, Zn, Ga, Mo, Pb) in larch tissues increase with an increase in atmospheric pollution. The correlation coefficient for needle nodes is not lower than 0.8 while no such correlation is observed for soil. An inverse correlation was established for biophilic element Mn: the higher is environmental pollution; the lower is its content in larch tissues. The accumulation of heavy metals in the organs of larch increases in the row: young sprouts–needles–buds.

### INTRODUCTION

Investigation of industry-caused pollution and the response of the living component of ecosystems is one of the most urgent problems of geoecology. Investigation of atmospheric pollution is hindered due to the high mobility of air mass, superposition of plumes from local, regional and global sources.

In order to carry out a correct investigation of the system atmospheric pollution – response of ecosystems, we chose an object with the limited number of steady sources of pollution in the absence of other pollutants within a radius of ~1000 km, among the primeval taiga ecosystems of Southern Yakutia. The goal of investigation was to reveal the features of the effect of atmospheric pollution produced by

coal-mining and fuel-energy industry of the Neryungri FEC on the taiga ecosystems. Multiaspect ecological and geochemical investigations were carried out in 2002–2003. The Neryungri FEC is limited within a quadrangle with the area of ~71.5 thousand hectares with the geographical coordinates of angles: longitude 124° 20', latitude 56° 00' – longitude 125° 30', latitude 56° 00'; longitude 124° 20', latitude 57° 10' – longitude 125° 30', latitude 57° 10'.

The position of the region under consideration at the junction of two climatic zones (the continental East Siberian and monsoon Far East) predefines climatic features. The wind direction prevailing in the mean annual (multi-year) and mean winter wind rose is northwest, annual mean wind velocity is

~2.4 m/s. In the surface layer of the atmosphere (500–1000 m) wind velocity increases (the annual mean value is 9 m/s); the directions prevailing in the wind rose are northern [1, 2].

The area under investigation is a region of continuous and discontinuous permafrost. The following types of soil are prevailing: mountainous podzol and the taiga brown soil, either typical or podzol on terrigenous rocks, sod-carbonate soil on carbonate rocks. The ecosystems of high-altitude zoning type are developed, from mountainous taiga to mountainous tundra with the prevalence of larch (*Larix cajanderi* Mayr.), birch (*Betula divaricata*) and bushes (*Vaccinium* sp.) [3].

The industrial development of Neryungri area started from coal deposit mining in 1975. The Neryungri coal open-pit mine occupies an area of ~4.4 thousand hectares; about 60 % of its area is covered with refuse heaps which are formed at the outer boundary of the mine in two layers about 70 and 50 m high. Total volume of the heaps was 1 231 859 thousand m<sup>3</sup> in August 2002. Blasting operations are regularly carried out at the mine; up to 30 thousand t of explosives is used and up to 42 thousand m<sup>3</sup> of rocks are blasted every year. Separation of coal into coking and power-generating material is carried out at the concentrating mill, which is situated at the industrial territory of the coal open pit mine. As a mean, up to 5 mln t of coking coal and 1.7 mln t of power-generating coal are processed annually. The main source of emissions of the mill is the drying and kindling workshop (the height of boiler tube is 62 m).

The power-generating coal is the main fuel for the Neryungri power plant, which supplied energy to the industrial works of Yakutia and the Amur Region. The height of the tube of the NPP is 236.4 m; its diameter is 8.4 m. The Neryungri hot-water plant (with the tube 150 m high and the diameter of 4.8 m), Chul'man heat stations were built to provide heat for the city of Neryungri and Chul'man settlement. The main characteristics of the constituents of the Neryungri fuel and energy complex are shown in Table 1.

The South Yakutian Highway and the branch of the Amur-Yakutia railroad are linear bodies affecting a narrow land band all over their length. Gold mining is carried out in local sites of river valleys with the help of the gravitation method. Due to thin population of the Neryungri ulus (according to the data of 2002, there are 72.6 thousand persons per 98.9 thousand km<sup>2</sup>, or 0.7 person per 1 km<sup>2</sup>, inhabitants of Neryungri and Chul'man accounting for 98.3 % of the population), anthropogenic load on ecosystems is estimated to be insignificant. Therefore, the main sources of man-made influence on the vast taiga ecosystems of the region are the works of the Neryungri fuel and energy complex.

Remoteness of the territory by thousands kilometers from other industrial regions, a single type of man-made action on ecosystems, a short history of industrial development and the availability of the necessary meteorological data allowed us to obtain an adequate quantitative model of regional pollution with the help of

TABLE 1

Characteristics of the objects of the Neryungri Fuel and Energy Complex (according to the data of the Neryungri Administration of Nature Conservancy)

Object	Fuel consumption in 1996–2001, t/y		Emission into the atmosphere t/y	
	Coal	Black oil	2000	2001
The Neryungri coal mining pit	–	–	1922*	1857*
Concentrating mill	73 800**	1200**	1876	1884
The Neryungri power plant	1 196 822	8385	10 711	11 826
The Neryungri water-boiling plant	39 920	3	1661	1113
The Chulman power plant	130 864	9	1776	1412

\* The data calculated without taking into account the emissions during blasting operations.

\*\* The data from the Department of Ecology of the Concentrating mill of the Neryungri coal mining pit.

mathematical modeling, and to verify the model experimentally.

## EXPERIMENTAL

The mathematical modeling by formulating the direct task was carried out on the basis of OND-86 procedure, which was developed at the A. I. Voeikov Principal Geophysical Observatory (St. Petersburg) [4-6]. The concentration of a substance in the surface layer of the atmosphere  $C(r, \varphi)$  (in  $\text{mg}/\text{m}^3$ ) from a point source was calculated in each point of the ground using equation

$$C(r, \varphi) = c'(r, u_1, k_1) \times \exp[-(\varphi - \varphi_0)^2 / (2\varphi_0^2)] / (2\pi^{1/2}\varphi_0 r)$$

where  $u_1$  and  $k_1$  are wind velocity and the coefficient of vertical exchange in the surface layer of the atmosphere at the height  $z_1$  (usually 1 m), respectively,  $\varphi_0$  is dispersion of fluctuations of wind directions for 20-30 min,  $\varphi$  is the azimuth of plume axis,  $r$  is the distance from the source,  $c'$  is the concentration from an infinite linear source oriented perpendicularly to wind direction, with the specific capacity per unit length equal to the capacity of the point source under consideration. The  $c'$  value is determined by solving the equation of atmospheric diffusion.

When modeling, we considered the versions taking into account two wind roses in the surface layer at the meteorological station in Chul'man according to the data of many years (1966-1980) and the short-term data (1996-1998). For the boundary atmospheric layer at a height of 500 to 1000 m, the wind rose obtained by high-altitude probing was taken into account [1, 2].

Mathematical modeling by formulating the inverse problem was carried out on the basis of the data on dust content of snow cover in one geo-assigned point using the program developed in [7, 8].

Let axis  $x$  be directed to the east, axis  $y$  to the north; let  $S$  be an in-plane source of impurities. The concentration of a weakly precipitating impurity during a long time interval (a month, a season, a year) at a significant distance from the point source will be described with the help of equation [8, 9]

$$q(x, y) = \frac{m(\xi, \eta)P(\varphi(x, y, \xi, \eta) + 180^\circ)}{2\pi u H \sqrt{(x - \xi)^2 + (y - \eta)^2}} \quad (1)$$

where  $\varphi(x, y, \xi, \eta) = \arctg \frac{y - \eta}{x - \xi}$ ,  $(\xi, \eta)$  are the coordinates of the source,  $(\xi, \eta) \in S$ ,  $m(\xi, \eta)$  is emission of an impurity from this point,  $P(\varphi)$  is the wind rose during the time interval under consideration at the height of the boundary layer,  $u$ ,  $H$  are the mean wind velocity and the height of mixing layer, respectively.

Point  $(x, y)$  is supposed to be at a distance of more than 7-10 km from the source. In this case, equation (1) provides rather reliable description of long-term environmental pollution for such a distance.

Taking into account equation (1), we may represent the concentration of the area source  $S$  as

$$Q(x, y) = \frac{1}{2\pi u H} \iint_S \frac{m(\xi, \eta)P(\arctg \frac{y - \eta}{x - \xi} + 180^\circ)}{\sqrt{(x - \xi)^2 + (y - \eta)^2}} d\xi d\eta \quad (2)$$

Here we also assume that point  $(x, y)$  is located at rather large distance from set  $S$ .

As a rule, the  $m(\xi, \eta)$  function is unknown or is rather approximately known. In this case, interpretation of the data of observations with the help of equation (2) is complicated. The situation may be improved substantially if we transform equation (2) using the generalized mean value theorem from integral calculus. According to this theorem, the following equality is true for two arbitrary continuous functions on a connected compact set:

$$\iint_S f(\xi, \eta)g(\xi, \eta)d\xi d\eta = f(\lambda, \mu) \iint_S g(\xi, \eta)d\xi d\eta \quad (3)$$

where  $(\lambda, \mu) \in S$  and it is assumed additionally that  $g(\xi, \eta) \geq 0$  on set  $S$ .

In the case under consideration, assuming that  $g(\xi, \eta) = m(\xi, \eta)$

$$f(\xi, \eta) = \frac{P(\arctg \frac{y - \eta}{x - \xi} + 180^\circ)}{\sqrt{(x - \xi)^2 + (y - \eta)^2}}$$

we obtain a simple relation

$$Q(x, y) = \frac{\theta P(\arctg \frac{y - \mu}{x - \lambda} + 180^\circ)}{\sqrt{(x - \lambda)^2 + (y - \mu)^2}} \quad (4)$$

where  $\theta = M/(2\pi uH)$ ,  $M = \iint_S m(\xi, \eta) d\xi d\eta$

is total emission of the impurity from the area source.

Analysis of dependence (4) shows that in order to determine function  $Q(x, y)$ , it is sufficient to estimate unknown parameters  $M$ ,  $\lambda$ ,  $\mu$ , for example, using the data of observations. The situation can be simplified substantially if the position of a prevailing point source at the territory is known. In this case,  $\lambda = x_0$ ,  $\mu = y_0$ , where  $x_0$ ,  $y_0$  are the coordinates of the effective source.

The models thus obtained were tested by checking the convergence between the calculated and experimental data on dust content of snow (in g/l) over 22 points (excluding the reference point).

Sampling from the turf horizon A0 and from the humus horizon A1 and from larch (*Larix cajanderi* Mayr.) was carried out in the dry and sunny days in August 2002 and 2003.

Soil samples (66) were placed in canvas sacks and dried under field conditions to the air-dry state. Larch samples (51) were collected from branches in a uniform manner at a level of 1.5–2 m from the trees 6–7 cm in diameter, of approximately the same age. After purification from impurities, the samples were dried at room temperature till air-dry state [10, 11].

In order to study the elemental composition of the samples, X-ray fluorescence method was used, involving the synchrotron radiation at the station of elemental analysis of VEPP-3 in the Budker Institute of Nuclear Physics, SB RAS (Novosibirsk). After drying till constant mass, soil samples with a mass of 200 g were ground to 200 mesh, weighed portions (30 g) were taken and pressed in tablets (6 mm in diameter). Samples of needles, needle nodes and young larch branches were concentrated before tableting by ashing in the sparing regime (slow heating to 350 °C for 2 h) in order to conserve high-volatile components. When calculating the concentrations of elements, we used the international reference soil sample SOIL-7 of the IAAE, the Russian reference of gramineous plants ZSBMT-02 No. 3170–85. The relative standard deviation of the concentrations of above-listed elements is 10–15 %, the lower

detection limit is down to 0.1 ppm, depending on the excitation energy of emission lines.

Analysis for the nitrogen content of larch needles was carried out in the Laboratory of Microanalysis of Novosibirsk Institute of Organic Chemistry (NIOCh), SB RAS (Novosibirsk) with an automatic element CHN analyzer (Carlo Erba company, model 1106, Italy). The method is based on the high-temperature oxidative destruction (1100 °C) of the organic sample (powdered), separation of destruction products with a chromatographic column and determination with the thermal conductivity detector. The procedure was been metrologically certified at the Ural SRI of Metrology in accordance with the State Standard (GOST) No. 8.563–96. Relative error was 7 %, the lower detection limit 0.1 % mass.

Analysis for the sulphur content of larch needles was carried out at the NIOCh, SB RAS. The method is based on the high-temperature (1300 °C) oxidative decomposition (incineration) of the organic sample in a flask filled with oxygen (Scheniger procedure). The resulting sulphate ion is determined by titration with the solution of barium nitrate in the presence of chlorophosphnaza III indicator. The procedure was certified in accordance with GOST P8.563–96 at the Ural SRI of Metrology. Relative error was 20 %, the lower detection limit 0.01 mass %.

Computer versions of the model of atmospheric pollution of the NFEC territory with the actually measured data on dust content of the snow cover, and with the results of analyses of soil and plant samples were imposed onto a geo-coded map with 1 : 100 000 scale (with real geographic coordinates) to give a united GIS project using the SGIT programme (the GIS Centre of the UIGGM, SB RAS, Novosibirsk) and the GIS system of coding Envi (USA), as well as the system of interpolation of spatially-bound data ArcView3.2 (ESRI, USA).

## RESULTS AND DISCUSSION

Solution of the direct problem of mathematical modeling allowed us to contour the plumes of atmospheric pollution extended mainly in the southeast, both in the annual

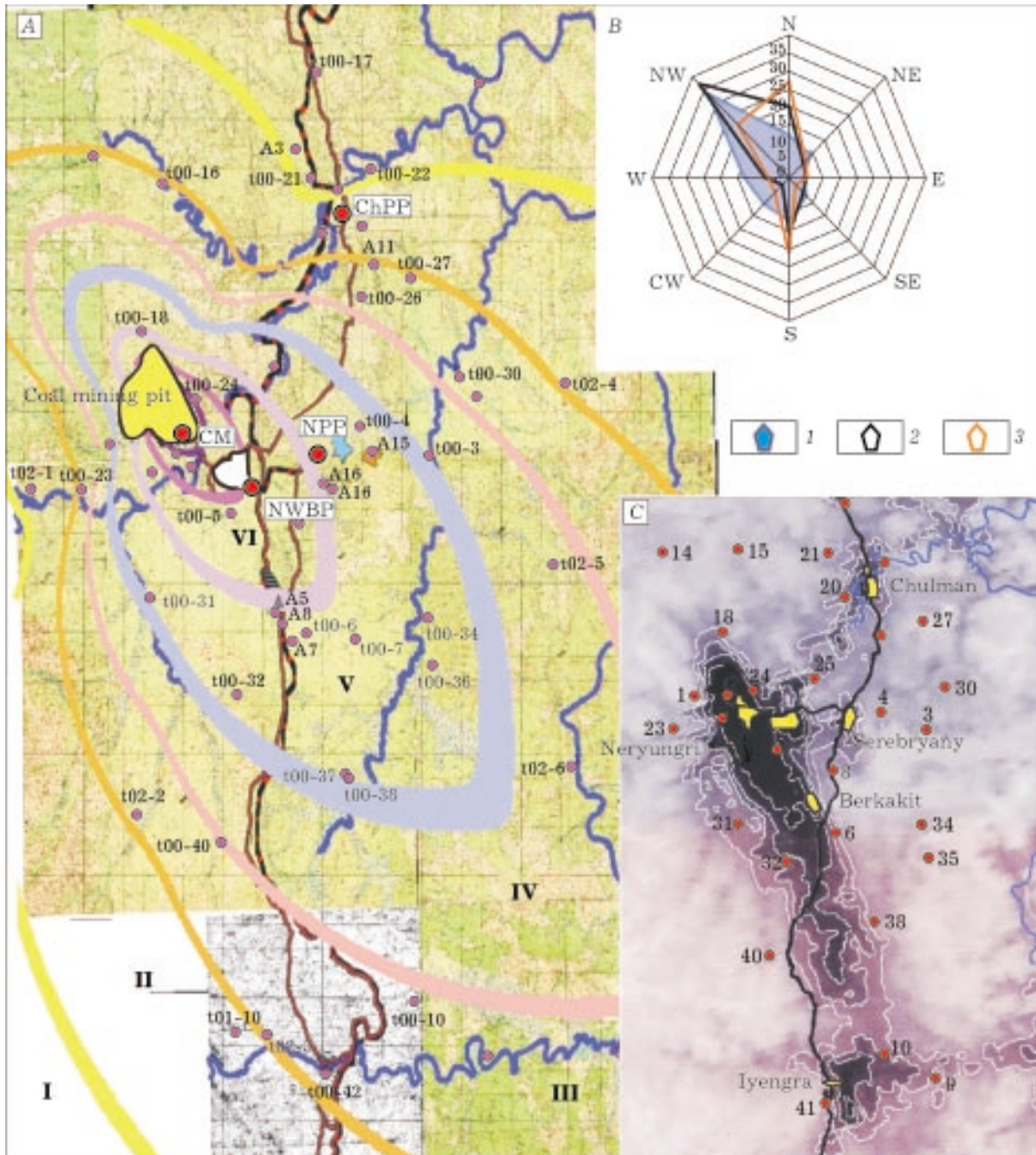


Fig. 1. Territory of the Neryungri fuel and energy complex: A – the GIS model of atmospheric pollution with the zones characterized by different dust content of the snow cover (ChPP – the Chulman power plant, NPP – the Neryungri power plant, NWBP – the Neryungri water-boiling plant, CM – concentrating mill of the Neryungri coal mining pit); B – the wind rose (m/s) in Chulman during the years: 1946–1960 (1), 1966–1980 (2), 1996–1998 (3); C – a space image taken by Institute of Cosmophysical Research and Aeronomy, SB RAS, April 21, 2001. For explanations, see the text.

mean temporal section and in the section across the winter period. Pollution with  $\text{SO}_2$  is the most hazardous one for conifers [12]. According to the model,  $\text{SO}_2$  content in the valley of the Semenovskiy stream to the southeast from the Chul'man heat station reaches  $0.03 \text{ mg/m}^3$ , or 1.5 MPC adopted for plants [13]. The zone with

$\text{NO}_2$  pollution is situated here, too; the concentration of this pollutant is at the MPC level  $\sim 0.04 \text{ mg/m}^3$  (Fig. 1). The high chimneys of the Neryungri power plant and water-heating boiler provide mixing of their emissions in a large air volume, so no regions with the concentrations exceeding the MPC are formed.

TABLE 2

The coefficients of comparison between the calculated and measured data on the dust content of snow cover over the territory of the Neryungri fuel and energy complex

Parameter	Version 1	Version 2		Version 3		Version 4	
	RP 1	RP 7	RP 36	RP 36	RP 27	RP 8	RP 7
$K_{\text{reg}}$	0.98	4.17	5.82	3.44	56.05	2.97	10.37
$K_{\text{zon}}$	1.01	1.34	1.86	0.77	12.59	1.38	4.82

Note. RP means reference point.

The southeast side off the coal open-pit mine including the valley of the Chul'man river near the mouth of the M. Berkakit and the valley of the Amunakty to the southeast off the city of Neryungri are heavily polluted not only with dust but also with gas emissions from the concentrating mill. The field of maximal dust concentrations ( $0.14 \text{ mg/m}^3$ , to be compared with the MPC of dust  $0.15 \text{ mg/m}^3$  for humans [14]) in the surface layer of the atmosphere is formed to the south-east from the city of Neryungri at a distance of 1–4 km: in the valley and at the right bank of the Amunakty river.

When solving the inverse problem, we considered the versions of calculations in which the main objects of the Neryungri FEC are in turn accepted as the effective (predominant) pollution source. In each version, a reference point was chosen which was located along the direction of prevailing northwest winds (to the south-east from the object) at a distance of 7–13 km.

Finally, by the end of winter (in g/l of melted snow), four versions of the data on the dust content of snow cover were obtained in each of 179 361 points distinguished in the network over the NFEC territory.

Estimation of the degree of reality of the considered model versions was carried out. To do this, we calculated the coefficients for comparing the data on the dust content of snow cover, both the model calculated values and actually measured ones,  $K_{\text{reg}}$  over 22 points:

$$K_{\text{reg}} = \frac{\sum_{i=1}^n (\theta_{\text{meas. } i} / \theta_{\text{calc. } i})}{n} \quad \text{and } K_{\text{zon}} \text{ for the points}$$

nearest to the effective source within the radius of not more than 10–13 km:

$$K_{\text{zon}} = \frac{\sum_{j=1}^m (\theta_{\text{meas. } j} / \theta_{\text{calc. } j})}{m} \quad (5)$$

where  $m = 2-6$ .

Version 1 (Table 2) turned out to be the most adequate one. In this version, the open-pit coal mine with the concentrating mill, represented as a united steady area source by imposing 2361 points, was accepted as the effective one. In this version, the level of correspondence between the actually measured dust content values and calculated ones turned out to be the highest:  $K_{\text{reg}}$  and  $K_{\text{zon}}$  values are close to 1 (see Table 2). The difference between the measured and calculated values does not exceed 53 % as a mean. Calculated values are higher than the actually measured dust content of snow in 15 of 22 samples, which may be due to the correction for the surface slope, exposure, percentage of forest land and other natural factors. In seven cases, actually measured values are higher than the calculated ones, which are explained by the vicinity of sampling sites from the local linear source (road) and its additional contribution into regional pollution.

Other versions of the models of atmospheric pollution exhibit substantial deviations from the observation data, as  $K_{\text{reg}}$  and  $K_{\text{zon}}$  deviate from 1 essentially. So, only one model (version 1) provides the most adequate description of the actual atmospheric pollution over the NFEC territory. According to this model, blasting operations at the open-cast mine of the Neryungrinskiy pit and emissions from the concentrating mill are predominant sources of atmospheric pollution over this territory. The contribution from heat-and-power plants – the Neryungri power station, Chul'man heat station and the Neryungri water-heating boiler which were previously considered to be the main sources of pollution [15] is less essential.

The plume of the winter mean atmospheric pollution is extended in the southeast direction for more than 80 km from the coal mine, its width does not exceed 40 km (in agreement with

the wind rose) and coincides with the pollution plumes revealed by formulating the direct problem (see Fig. 1). The contours of this plume coincide rather well with the reflectance of snow-covered surface recorded from the satellite in spring (space photograph by Institute of Cosmophysical Research and Aeronomy (IKFIA), SB RAS, Yakutia) because changes in reflectance during snow melting are proportional to the level of snow cover pollution.

We distinguished the following zones in the plume of atmospheric pollution: I – with extremely high pollution (the dust content of snow: 0.4–0.7 g/l), II – with high pollution (0.2–0.4 g/l), III – with moderate pollution (0.1–0.2 g/l), IV – polluted (0.1–0.07 g/l), V – slightly polluted (0.05–0.07 g/l), VI – practically unpolluted (0.03–0.05 g/l), VII – background (less than 0.03 g/l).

The metal content of soil and plants was investigated in the zones distinguished on the basis of modeling results.

In soil, the range of heavy metal (HM) concentrations is very wide. The higher is the extent of industry-related pollution of a zone, the larger are the concentrations of Fe, Cr, Ni, Mo in the humus horizon of soil (with the correlation coefficient not lower than 0.66) (Fig. 2). In the zone with extremely high pollution (I), the concentration of iron in soil is at a level of 53.2–54.1 g/kg, while in the background zone (VII) it is about 40.6–41.5 g/kg. The concentration of Mo in the soil of zone I is up to  $(21.7 \pm 2.1)$  mg/kg, while in the background zone (VII) it is about an order of magnitude lower –  $(2.82 \pm 0.3)$  mg/kg, the Clarke of Mo being 2 mg/kg [16]. For other HM, no dependence of their concentrations in soil on

the extent of atmospheric pollution is observed. The soil MPC levels are not exceeded even in the soil of the most heavily polluted zone.

It was revealed that the distribution of manganese over A0 and A1 horizons has a regular character: Mn concentration in the turf horizon is much higher ( $(2.14 \pm 0.21)$  g/kg) than in the humus horizon ( $(0.84 \pm 0.07)$  g/kg).

Chemical composition of plants depends mainly on the ability of a plant to accumulate one or another element, including biophilic heavy metals (copper, cobalt, etc.) participating in plant metabolism. Natural factors determining chemical composition of plants include the composition of soil, underlying rocks, the landscape position, climatic and weather conditions (rains promote washing out, dry weather helps accumulation of the elements due to increased transpiration), and the aerosol composition of the surface atmospheric layer, intensity of dust precipitation and its chemical composition.

Among pollutants, the compounds deserving attention are nitrogen- and sulphur-containing components of the products of combustion of fuel and explosives, since these components affect vegetation [12–14]. To the southeast from the concentrating mill (the valley of the Chul'man river near the mouth of the M. Berkakit river) and to the southeast from the Chul'man power plant (the valley of the Semenovskiy stream), that is, in the regions where the concentrations of nitrogen and sulphur oxides in the surface air layer exceed the MPC or are close to them, according to modeling results, an increase in the mass concentration of S in larch needles is observed, %:  $0.3 \pm 0.06$  and  $0.215 \pm 0.043$ , respectively, in

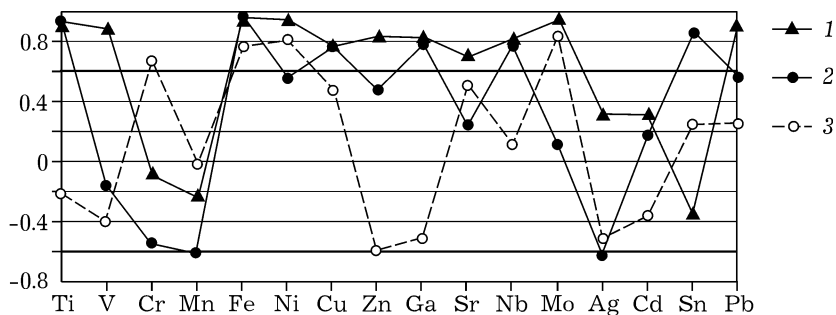


Fig. 2. Correlation coefficients for the data on the dust content of snow cover and the concentrations of heavy metals in needle nodes (1), larch needles (2) and the humus horizon of soil (3).

TABLE 3

The ratios between the concentrations C of various heavy metals in larch needle nodes, needles and branches at the territory of the Neryungri fuel and power complex

Concentration ratios						
~1	1.5-2	2-3	3-5	5-10	More than 10	
<i>In needle nodes/in needles</i>						
K, Ca, Rb, Sr, U	V, Cr, Ni, Cu, Bi	Mn, Zn, Ag	Ti, Ga, Y, Mo, Cd, Tl	Pb, Th, Zr	Fe, Sb, Nb, Sn	
<i>In needle nodes/in branches</i>						
K, Ca, Rb, Sr, U,	V, Mn, Zn	Ga, Mo, Y, Cd	Ti, Cr, Fe, Zr, Pb, Th	Tl	Nb, Sn, Sb	
Ni, Cu, Ag, Bi						

comparison with  $0.11 \pm 0.02$  at the background region. Also, an increase in the mass concentration of sulphur in larch needles was observed near the ash dump of the Neryungri heat station (the basin of the Olongoro river) – about  $(0.25 \pm 0.05) \%$ . So, under atmospheric pollution, sulphur content of larch needles increases by a factor of 2–3 in comparison with the background level. A similar situation is observed with fir needles (*Picea obovata* Ledeb.) in the Kemerovo Region [17].

According to the mathematical model, the contoured regions of pollution with  $\text{SO}_2$  at the territory of the Neryungri FEC coincide with the regions where larch trees with increased sulphur content of needles grow, which also confirm the adequate character of the model.

The concentrations of nitrogen in larch needles is about an order of magnitude larger than the concentrations of sulphur with a narrower variation range, % mass: from  $1.72 \pm 0.12$  in the background zone (VII) to  $1.92 \pm 0.13$  to the southeast from the coal open pit,  $2.12 \pm 0.15$  in the valley of the Semenovskiy stream to the south-east from the Chul'man power plant, and up to  $2.49 \pm 0.17$  in the basin of the Olongoro stream near the ash dump of the Neryungri power plant. In the zones with lower pollution, the concentration of nitrogen in larch needles is at the background level. So, under strong atmospheric pollution the maximal increase in nitrogen content of larch needles is only about 45 % of the background level, while sulphur content increases nearly by a factor of 3. This suggests that, in spite of the smaller portion of sulphur oxides in the emissions of the NFEC in comparison with nitrogen oxides, their effect on vegetation is much stronger.

Alkaline metals and alkaline earths, unlike HM, accumulate uniformly in larch organs (needle nodes, needles and branches). It was revealed that the concentrations of HM in needle nodes of larch are higher than those in needles and branches: as a mean, almost 10 times as large as those in needles and about 5 times as large as in branches (Table 3). A direct proportional dependence between HM concentrations is characteristic: the larger is metal concentration in needle nodes, the larger is its concentration needles and branches (the correlation coefficient is ~0.7). For Ti, Mn, Fe, Cu, Ga, Rb, Y, Zr, Nb, Th, the correlation coefficient is not less than 0.85. Since an element is most actively accumulated in larch buds, analysis of the spatial (zonal) changes in chemical composition of larch tissues was carried out over the territory of the Neryungri FEC on the basis of the composition of needle nodes of larch.

As the extent of mad-made pollution increases, the concentrations of HM in larch tissues increases, for example, in needle nodes, mg/kg: V 10–15, Ni 0.6–2, Cu 2–7.5, Zn 30–70, Ga 0.4–1, Mo 0.05–0.16, Pb 2.1–6. The concentration of Fe increases from 0.6 in the background zone to 2.3 g/kg in the zone with extremely high pollution (Fig. 3). A direct correlation was revealed between the concentrations of almost all the HM in larch tissues and the extent of industry-related pollution of zones with an average coefficient of 0.66, while in the upper soil horizons such a correlation is characteristic only of Fe, Cr, Ni, Mo (see Fig. 2).

A trend of decreasing Mn accumulation in larch tissues under man-made pollution was revealed: the concentration of Mn in the buds



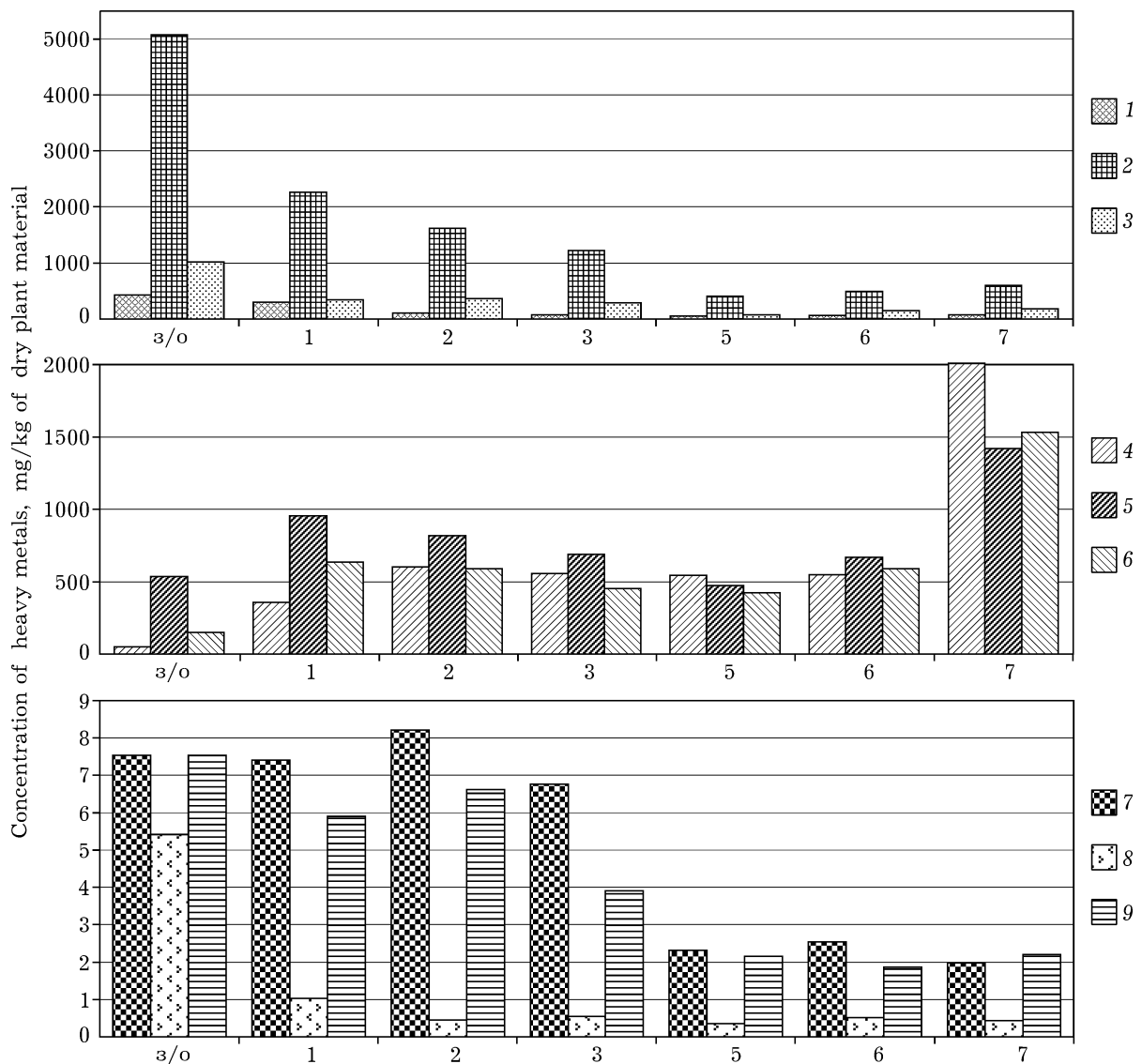


Fig. 3. Concentrations of heavy metals in larch tissues in the zone with very high (1) and high (2) extent of pollution, polluted (3), weakly polluted (5), almost pure (6), background zones (7), at the local region of extremely heavy pollution near the ash dump of the NPP (ad): 1–3 – Fe in the needles (1), needle nodes (2), branches (3); 4–6 – Mn in the needles (5), branches (6); 7–9 – Cu (7), Ga (8), Pb (9) in needle nodes.

of larch in the background zone is 1420 mg/kg, in the region with extremely high pollution about 960 mg/kg, while near the ash dump of the Neryungri power plant, a source of very heavy local pollution, it is only 534 mg/kg. The coefficient of inverse correlation is equal to  $-0.61$ . Such a behaviour of Mn was also observed in the needles of Siberian fir tree in the Kemerovo Region: Mn content decreases by a factor of 2.5–10 in polluted regions, in comparison with the reference site, while the concentrations of other HM increase [17].

## CONCLUSIONS

1. On the basis of the data on dust content of snow cover, an adequate quantitative model of atmospheric pollution was obtained; the model was approved experimentally. In agreement with the wind rose, the main plume of pollution is extended along the southeast direction up to 80 km, which is also confirmed by the coincidence between its contour and reflectance of the Earth's surface observed in the space image.

2. It was revealed for the first time that the prevailing source of pollution is the Neryungri coal mining pit where permanent blasting operations are carried all the time, but not the Neryungri power plant as it had been considered before. The position of the main settlement of the region, *i.e.* the Neryungri city, at a distance of 6 km to the southeast from the Neryungri coal mining pit (in the direction in which the plume of atmospheric pollution is formed) points to the presence of ecological risk for the health of local population.

3. The regions with increased SO<sub>2</sub> and NO<sub>2</sub> concentrations in the surface air layer to the south east from not very high sources – the Chul'man power plant, the concentrating mill of the Neryungri coal mining pit, and ash dump of the Neryungri power plant – were contoured. It was revealed that sulphur content of larch needles in these regions is three times higher, and nitrogen content is higher by about 45 mass % than the background levels.

4. It was revealed that an increase in the extent of atmospheric pollution is accompanied by an increase in the concentrations of all the heavy metals in larch tissues (with the mean correlation coefficient ~0.66), while in soil such a situation is typical only for several elements. In other words, larch tissues are better indicators of the extent of atmospheric pollution than soil.

5. The concentration of biophilic element – manganese – in larch tissues decreases with an increase in the extent of man-made pollution.

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