Mathematical simulation of the processes of aerosol pollution in the Lake Baikal region

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The annual deposition of heavy metals (hexavalent chromium, manganese, and copper oxide) on the surface of Lake Baikal was estimated. The contribution of individual sources of toxicants into pollution of the Southern Baikal and Baikal Reservation was determined. A significant influence of the studied region topography on heavy metal transfer was revealed.

Introduction

The problem of anthropogenic pollution of the environment is now very urgent throughout the world. Pollutants emitted by industrial enterprises and motor transport not only cause irreversible processes in natural media ("dead" lakes, unrecoverable soils, etc.), but exert extremely negative effect on the human vital activity. Some substances, such as sulfur and nitrogen dioxides, being emitted into the atmosphere, take part in formation of acids and acid salts, i.e., sulfates and nitrates. These substances can be transported by air masses to tens, hundreds, and sometimes thousands kilometers. Their gravitational deposition and precipitation in the form of acid rains increases the acidity of soils and waters, that leads to oppression and death of vegetation, animals, water inhabitants and causes different human diseases.

Accumulation of some heavy metals in organs and muscular tissues causes serious and sometimes fatal diseases. Lead compounds such as lead tetraethyl and others cause cerebral diseases, result in children mental disorders, affect central nervous system. Excess of the chrome concentration causes serious cancer illness, and excess of manganese concentration leads to osseous illness.

Quantitative estimation of deposition of hexavalent chrome, manganese, and cupric oxide on the South Baikal water surface in different seasons

Main sources of heavy metal emissions into atmosphere are coal combustion, motor transport, and steel foundry. The concentration of heavy metals in ashes of electric power stations, industrial furnaces, and home stoves is significantly greater than in soil.

Usually heavy metals and their compounds are in air in the form of finely dispersed submicron particles of 0.5–1 μm in diameter. They can be transported by air masses to significant distances (1000 km and more).[1] Falling down to water reservoirs or soil, heavy metal compounds negatively affect animals and vegetation, and, finally, local human population through food. Therefore, it is important to estimate the amount of such toxicants both in the vicinity of their sources and on the surface of water reservoirs.

Solution of this problem through measurements seems to be impossible, because to perform correct estimates, synchronous instrumental investigations with good horizontal resolution over the entire water surface are needed, that, evidently, is too expensive. Mathematical modeling of spreading admixtures simplifies the estimation of the amount of the metals and their compounds falling down during the period under study. Similar investigations were earlier conducted for other regions. The remote transfer models[1,2] were used in studying the spread of heavy metals over Europe. Some attempts were undertaken to estimate the anthropogenic fluxes of a series of atmospheric microelements to the Lake Baikal water surface[3] on the basis of simple balance relations and analytical solutions.[4] The simple trajectory model[6–9] was used to estimate contributions of 15 main industrial sources, located in the region of Lake Baikal, into dust and heavy metal pollution of the lake northern part.[5]

We studied the processes of propagation and deposition of hexavalent chrome, manganese, and cupric oxide in the region of Southern Baikal with the non-stationary spatial Euler model taking into account the effect of the local relief.[10–12] The sources of admixtures were industrial enterprises and complexes situated in stream valleys of Angara and Selenga, on the coast of Southern Baikal, and in the region of lake Gusinoe. The source parameters were set based on the inventory data.[13–19] Meteorological data were obtained by statistical processing of measurements at hydrometeorological stations.[20,21]

Numerical experiments were carried out for an area of 500×250 km and 5 km height over the surface of Lake Baikal. Temporal and horizontal steps were 150 s and 5 km, respectively. Vertical step was equal to 50 m up to the height of 300 m over the level of Lake Baikal, then it was 200, 1000, 1500, and 2000 m. The turbulent diffusion coefficients were calculated using the relationships of semiempirical theory of turbulence.[22]

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The mass emission rate of toxicants in the area under investigation was determined for each source individually and for their joint action by values of the toxicant concentrations calculated at each temporal step. The rate of particle gravitational sedimentation was taken from Ref. 23. The results of calculation are presented in Figs. 1–3 and in Tables 1 and 2.

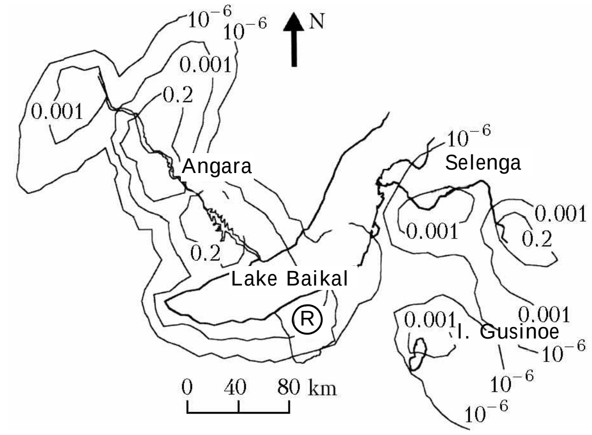

Fig. 1. Isolines of the Cr mass emission rate on the underlying surface of the region of Southern Baikal, (kg / km^2 · year). (R) – the territory of the Baikal Reservation.

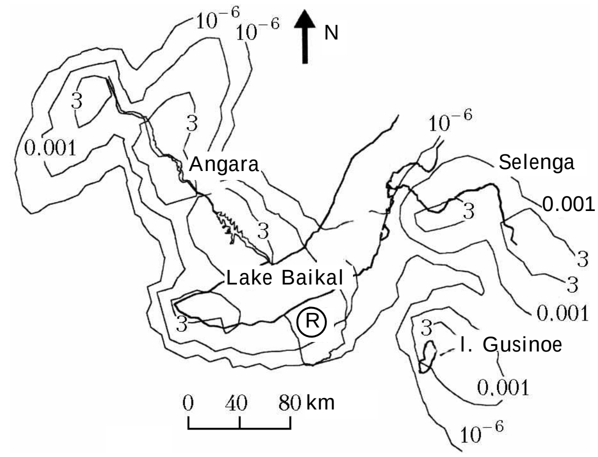

Fig. 2. Isolines of the Mn mass emission rate on the underlying surface of the region of Southern Baikal, (kg / km^2 · year).

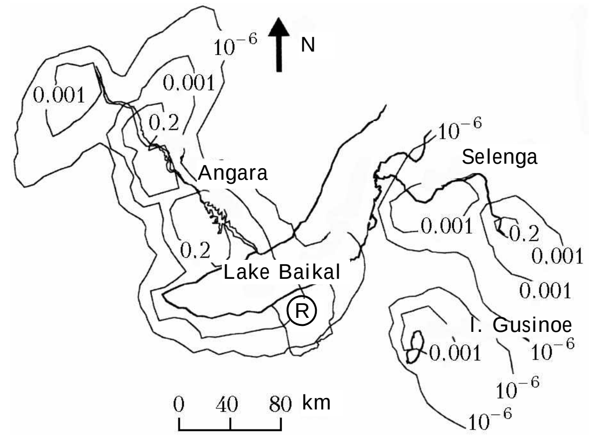

Fig. 3. Isolines of the CuO mass emission rate on the underlying surface of the region of Southern Baikal, (kg / km^2 · year).

Table 1. The contributions of Cr, Mn, and CuO into pollution of the Southern Baikal (dry deposition from the atmosphere), %

Source of emission	Contribution per year, %		
	Cr	Mn	CuO
Angarsk	7	1.5	3
Shelekhov	17	21	72
Irkutsk	74	60	20
Slyudyanka	1.5	16	3
Baikalsk	0.5	1.5	2

Figures 1–3 illustrate yearly distributions of the calculated fields of the mass emission rates for hexavalent chrome, manganese, and cupric oxide near the underlying surface of the region under study. The greatest values of fluxes of heavy metals are observed near the main sources of emissions situated in the valleys of Angara and Selenga.

The region under study includes the territory of the Baikal State Reservation (1657 km^2 area) formed in 1969 on the southern coast (between rivers Mishikha and Vydrinnaya) in the central part of the Khamar-Daban ridge.[24] The dark-coniferous taiga of fir and cedar is prevalent on the northern slopes of the ridge. Cedar and rhododendron brushwood and sub-alpine meadows dominate closer to the bald mountain zone, shrubs and lichen tundra grow higher. As a whole, there are 745 kinds of plants in the Reservation, many relict (for example, sweet poplar from neogen period) and endemic plants. Fauna of the Reservation is typical mountain–taiga, there are 37 kinds of mammal and 260 kinds of birds in the fauna composition. Reservations are the most effective form of preservation of the nature, their principal destination is to serve the standard of untouched or well-preserved nature and to be the place of the study of the behavior of natural processes and phenomena. All economical activity is prohibited on their territory, so the study of the processes of the propagation, transformation, and deposition of emissions from industrial enterprises over especially protected territories of Baikal region favors the solution of the problem of preservation of the Lake Baikal ecosystem.

The contribution of heavy metals into pollution of the Baikal Reservation from each source separately has been determined (dry deposition from the atmosphere) (Table 2).

Table 2

Source of emission	Contribution per year, %		
	Cr	Mn	CuO
Angarsk	10	2	5
Shelekhov	16	24	74
Irkutsk	74	72	21
Slyudyanka	< 0.1	2	< 0.1

The yearly masses of heavy metals under study (kg) deposited on the surface of the Southern Baikal (area of 9000 km^2) and the Baikal Reservation are presented in Table 3.

Table 3

Southern Baikal			Baikal Reservation		
Cr	Mn	CuO	Cr	Mn	CuO
7	72	3	2	17	0.7

In order to estimate the effect of the relief on the deposition of heavy metals in the region of Southern Baikal, numerical experiments were carried out with taking into account of the relief and without it. It has been shown that the mountain ridges surrounding Lake Baikal (Primorskii, Baikalskii, Khamar-Daban, etc.) essentially affect the transport of heavy metals. The relief decreases by more than 30% the deposition of these toxicants in the Southern Baikal and by 10% in the Baikal Reservation.

Conclusion

Thus, the performed calculation and estimates show that industrial enterprises of Irkutsk make principal contribution of Cr and Mn into pollution of the Southern Baikal: 74 and 60%, respectively. The contribution of enterprises of Shelekhov is less (17 and 21%, respectively). The sources of emission situated in Shelekhov make the greatest contribution of CuO (72%). The effect of Irkutsk is significantly less (20%). The enterprises of Irkutsk make principal contribution of Cr and Mn into pollution of the Baikal Reservation: 74 and 72%, respectively, and the enterprises of Shelekhov – 16 and 24%, respectively. The sources of emission situated in Shelekhov make the greatest contribution of CuO into pollution of Baikal Reservation – 74%. The contribution of the enterprises of Irkutsk is less (21%).

The results obtained can be used for working out conceptions of effective exploitation of Lake Baikal recreation resources, as well as for improvement of ecological situation in the region through regulation of the operation regime of industrial enterprises.

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