Analysis of impact of atmospheric pollution on the forest-swamp ecosystems of Siberian oil-producing regions

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The impact of oil production on the environment is considered using, as an example, the effect of atmospheric pollution due to burning of oil-well gas on landscapes typical of Siberian taiga. The analysis is based on an approach combining sanitary–hygienic and landscape–geochemical methods. The effect of oil production volume is considered. Landscape areas polluted by atmospheric emissions of soot and nitrogen dioxide are estimated.

Introduction

Analysis of territories exploitated by gas-and-oil companies[1] shows that chemical pollution of soil, waters, and atmospheric air is among technogenic factors that are most dangerous for the environment. Flare towers forming extensive plumes of aerosol pollution are situated all over the territory of the West-Siberian oil-and-gas province. Burning of oil-well gas in these towers produces very aggressive and dangerous agents of chemical pollution of the atmosphere.[2] Their negative effect is aggravated by fine products of incomplete combustion of hydrocarbons that are toxic, as well as soot emitted in great volumes. It is well-known that soot clogs respiratory stomas of needles. This causes shrinkage of coniferous trees because of the long life cycle of needles. Nitrogen oxides participate in formation of acid precipitation and favor photochemical synthesis of oxidants in leaves, whereas the direct action of nitrogen oxides leads to yellowing or browning of leaves and needles.[3] Acids activate heavy metals. This all decreases plant vitality. According to the data presented in Ref. 3, the plant growth is disturbed at the atmospheric concentration of nitrogen dioxide of 0.35 mg/m^3.

In this paper, we consider the ecological effect of oil production using, as an example, the effect of atmospheric pollution by soot and nitrogen dioxide on forest-swamp regions on the territory of the West-Siberian oil-and-gas producing province.

1. Methodical aspects of analysis

The current practice of solving such problems[4] is based on the use of sanitary-hygienic standards (maximum permissible concentration (MPC), etc.). However, application of these standards to estimation of the impact on the landscape with its wide biological variety is not justified. Therefore, in this work we use a complex approach to estimation of the environmental impact.[5] This approach combines the sanitary–hygienic[4] and landscape–geochemical[6] approaches. However, this complex approach requires a great bulk of ecological, cartographic, and other information on the state of environmental components. This information cannot be practically obtained without application of geographic information systems (GIS's) and GIS technologies.[7]

Pollution zones for different concentrations of pollutants in air[8] (in fractions of MPC or in units of relative mass normalized to the area) were determined by simulating the spread of pollutants in the atmosphere. Contours of these zones were superimposed onto the landscape maps, and the relative areas subject to pollution were determined using GIS tools. Such pollution zones were determined for soot and nitrogen dioxide at the oil-producing fields. Calculations were made by well-known OND–86 technique[4] with the allowance made for the wind rose. The regions of oil-producing activity in the taiga zone of Western Siberia include mostly forests; therefore, the landscape map of the territory is based on the forestry materials. In our studies, we used actual data on air pollution from ecological certificates of oil-production enterprises.

2. Brief characteristic of the object under study

As a studied territory, we took a zone having the area of 12 800 km^2 in the northwest part of Tomsk

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Region. Hereinafter, this zone is called a key zone (KZ). According to Ref. 5, the KZ territory is characterized by high hydromorphism, low values of bioclimatic potential, and weak stability of ecosystems to external factors. The landscape structure of the KZ territory is formed by progressive formation of swamps in the central part of watershed plains and by drainage activity of not numerous rivers and brooks[2] and determined by interosculation of forest and swamp landscape areas. Swamp landscapes occupy about 40% of the KZ area. They are mostly large oligotrophic swamps forming a common tract of swamp.

As is seen from Table 1, more than 90% of the KZ territory is occupied by three types of natural landscapes: dark-coniferous–small-leaved forest (DSF), pine forest (PF), and upper swamps (US). That is why below we present the calculated results only for these types of the landscape.

Table 1. The landscape structure of the key zone territory

Type of landscape	DSF	PF	US	Lower swamp	Transient swamp	Flood-lands of River Vasyugan
Normalized area, in %	51.7	4.8	37.9	0.3	1.4	3.9

Nowadays several oilfields are functioning on the KZ territory, and oil-well gas is burned in flare towers there. Thus, the Pervomaiskoe oilfield emits annually 388 tons of soot and 63 tons of nitrogen dioxide into the atmosphere. A total of 537 tons of soot and 130 tons of nitrogen dioxide is emitted into the atmosphere from the KZ territory a year.

An object of analysis in this paper is the polluted area related to the total one for different types of landscape (within KZ). Certainly, this relative area depends both on the level of pollution (in fractions of MPC) and on the oil production volume, as well as on the volume of the burned gas. The level of pollution here is the pollutant concentration in air referred to the corresponding MPC.

3. Influence of oil production volumes on the size of area polluted

The areas of different types of natural landscapes in the pollution zone were derived from the actual values of emissions from all flare towers. For the levels of pollution equal to 0.1, 0.3, and 0.5 (fractions of MPC) we calculated the ratios of areas polluted by soot or nitrogen dioxide emissions to the total area of a given type of landscape as a function of the oil production volume (Figs. 1 and 2).

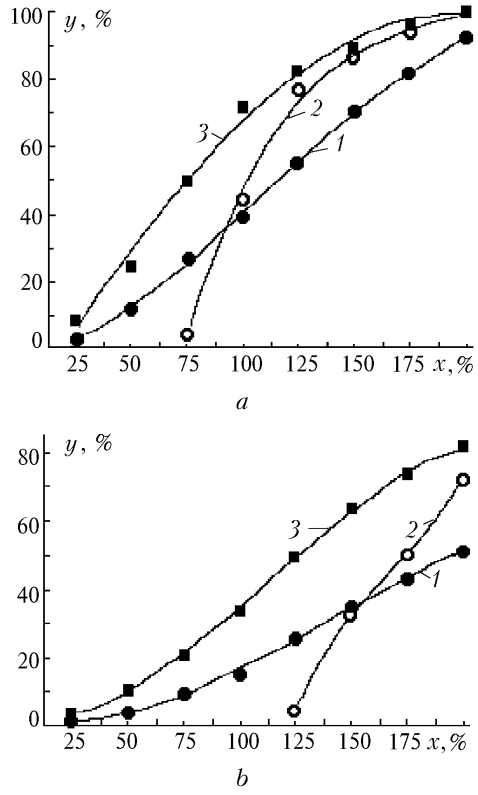


Fig. 1. Relative area polluted by soot emissions vs. oil production volume x at 0.3 MPC (*a*) and 0.5 MPC (*b*): dark-coniferous–small-leaved forest (*1*), pine forest (*2*), and upper swamp (*3*).

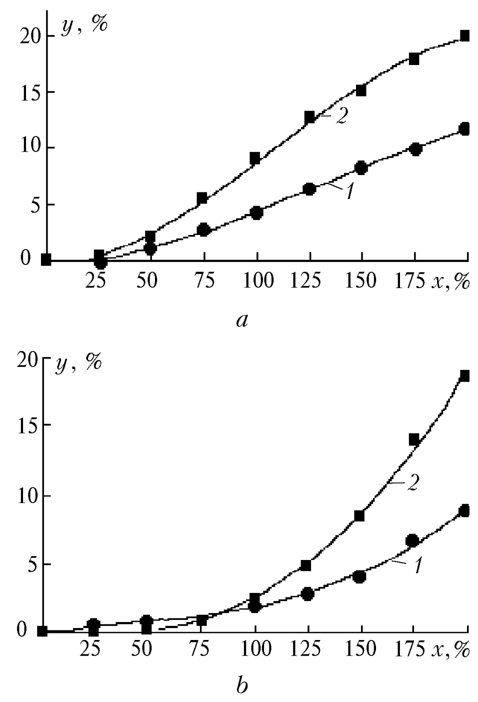


Fig. 2. Relative area polluted by nitrogen dioxide emissions vs. oil production volume x at 0.1 MPC (*a*) and 0.3 MPC (*b*): dark-coniferous–small-leaved forest (*1*) and upper swamp (*2*).

Table 2. Coefficients of polynomials for the data shown in Fig. 1

Type of landscape	Range of x	a_3		a_2		a_1		a_0	
		0.3	0.5	0.3	0.5	0.3	0.5	0.3	0.5
US	[25; 200]	−0.077	−0.291	−0.802	3.965	26.104	−3.276	−19.374	2.716
DSF	[25; 200]	−0.207	−0.154	2.782	2.567	2.889	−3.037	−3.21	2.544
PF	[0; 75)	0	–	0	–	0	–	0	–
	[75; 200]	0.823	–	−18.292	–	140.55	–	−275.32	–
	[0; 125)	–	0	–	0	–	0	–	0
	[125; 200]	–	2.277	–	−45.65	–	322.33	–	−750.36

Table 3. Coefficients of polynomials for the data shown in Fig. 2

Type of landscape	Range of x	a_3		a_2		a_1		a_0	
		0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3
US	[0; 200]	−0.265	0.019	4.242	0.163	−8.367	−1.018	3.509	1.014
DSF	[0; 200]	−0.106	0.022	1.972	−0.165	−4.231	0.79	2.344	−0.622

The obtained dependences (see Fig. 1) are well approximated by third-degree polynomials having the form

$$y = a_0 + a_1 x^1 + a_2 x^2 + a_3 x^3, \quad (1)$$

where a_0, a_1, a_2, and a_3 are the coefficients whose values are given in Table 2.

Processing of the calculated results on the areas polluted with nitrogen dioxide as functions of the oil production volume (see Fig. 2) shows that at the level of pollution corresponding to MPC the pollution zones are mostly localized within the territory of oilfields, and their diameter achieves 4 km with the total area of 35 km^2.

The decrease of the total volume of nitrogen dioxide emissions, as compared with that of soot, leads to a decrease of the pollution zone, and the pine forests that have relatively small area at the KZ territory (see Table 1) do not fall in the zones of pollution with nitrogen dioxide. This explains why we do not present the curves corresponding to them in Fig. 2.

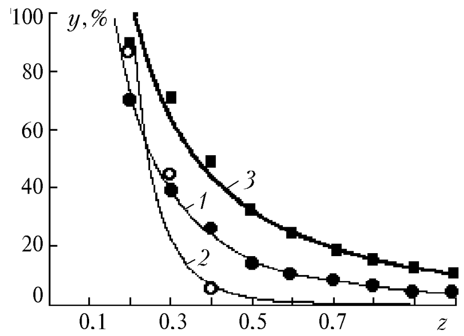
It is seen from Fig. 2 that the ratio y of the polluted area to the total one for a certain type of landscape as a function of the oil production volume is approximated by the third-degree polynomial of the form (1), as in the previous case. The coefficients of the approximating polynomials are given in Table 3.

4. Analysis of the impact of atmospheric pollution depending on the pollution level

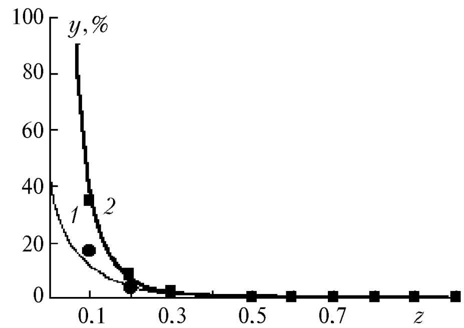
Let us consider the relative polluted areas for different types of landscape depending on the level of atmospheric pollution (in fractions of MPC). The calculated results are shown in Fig. 3. It is seen from the figure that the dependences of the relative polluted area y on the pollution level z are rather well approximated by the family of exponential functions having the form

$$y = A z^B, \quad (2)$$

where z is the air pollution level (in fractions of MPC); A and B are the coefficients whose values are given in Table 4.



a



b

Fig. 3. Relative area y of polluted landscape vs. pollution level z: soot (*a*) and nitrogen dioxide (*b*) emissions; dark-coniferous–small-leaved forest (*1*), pine forest (*2*), and upper swamp (*3*).

Table 4. Approximation coefficients for the data shown in Fig. 3

Type of landscape	A		B	
	soot	NO_2	soot	NO_2
DSF	864.17	44.397	−2.24	−2.05
PF	52244	–	−5.57	–
US	699.82	922.84	−1.72	−4.49

Conclusion

According to our calculations, the relation between the oil production volumes and the polluted areas is nonlinear. Thus, for example, if oil production is to be doubled, then a more than two times increase of the area polluted with soot should be expected. The estimation of atmospheric emissions from all oilfields on the KZ territory has shown that the distribution of pollutants over the territory is rather inhomogeneous, and high concentrations of pollutants can be observed even beyond the territory of oilfields due to superposition effects.

From analysis of the calculated data, it is seen that atmospheric pollution due to burning of the oil-well gas affects the state of the air basin at long distances from an oil-production place. The pollution zones of several oilfields often superimpose and merge into a joint West-Siberian soot spot. Besides, sites with very high pollutant concentrations can be formed at long distances from sources because of superposition of pollution zones. The joint analysis of the pollution zones and landscape situation allows us to find the territories subjected to high anthropogenic loads.

Consequently, the considered approach that takes into account the oil production dynamics allows the ecological load onto different types of landscape to be evaluated in time as a function of the relative pollution. The capabilities of GIS permit revealing the sites of maximum load with due regard for the specific features of the territory. The obtained results can be used when choosing points for ground-based monitoring, developing monitoring programs, and evaluating possible consequences of oil production on the territories with a similar landscape structure.

Acknowledgments

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