Evaluation of the impact of atmospheric pollution on the forest in oil-producing regions by use of images taken from space

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We consider methodical issues of analysis of the ecological impact of atmospheric pollution caused by petroleum gas flares in oil fields on forests using geoinformation systems and images from space. The landscape structure of oil-producing territories in Southwestern Siberia is determined based on processing of medium-resolution images obtained from Resurs-O1 satellite. Simulated data are compared with those obtained during long-term measurements of aerosol concentrations in Western Siberia performed by the Institute of Atmospheric Optics SB RAS. Relative areas of polluted landscapes are determined depending on oil production rates.

Introduction

Chemical pollution now is among significant impacts of oil production on the environment,[1] and burning of petroleum gas in flares on oil fields is the main source of aerosol pollution of the atmosphere in Siberian oil producing regions.[2,3] The GIS approach to evaluation of the effect of atmospheric pollution on the environment was developed in Ref. 4 based on the combination of the health and landscape-geochemical approaches. The use of this approach yielded quantitative estimates of the relative polluted forest and wetland areas on the territory of the Western Siberia. However, this approach assumes the use of landscape maps, whose drawing by traditional methods is an expensive and long process.

Use of space images makes obtaining the landscape information much faster and cheaper as compared with the use of expensive landscape maps, as shown in Ref. 5, which considered the issues of using high-resolution space images (SI). However, methodical issues of using medium-resolution space images for evaluation of the oil production impact on the environment are insufficiently covered in the research literature. The use of such SI is preferable when studying the landscape structure of extended territories, since one such space image makes it possible to study the territory up to 300 000–350 000 km^2, which is quite promising for the conditions of Siberia.

In this connection, the objective of this work was the development of methodical issues of using medium-resolution space images for analysis of the oil production impact on the environment and considering some results of evaluation of the ecological impact of chemical pollution of the atmosphere caused by petroleum gas flares on forests and wetlands in Western Siberia.

1. Methodical issues of decoding the medium-resolution space images

As shown in Ref. 5, the use of space images is efficient when solving problems on a complex monitoring of forests and wetlands and determining the landscape structure of hard-to-reach territories, whose ground-based investigations are very long and expensive. Space images widely used in studying and mapping forest resources allow organization of regular monitoring of forests, including monitoring of changes under the effect of both natural factors and activity of oil production and other industries.

In this paper, to draw the landscape map of the territory and determine the forest and wetland areas, we used multichannel medium-resolution images from the Resurs-O1 satellite (MSU-SK scanner). As a topographic basis, we took the M 1:1000000 map made by Roskartografiya. The MSU-SK space image with the spatial resolution of 150 m has the 600-km swatch. The MSU-SK scanner with four spectral channels (channels 1–3 in the visible spectrum, channel 4 in the near infrared) allows distinguishing among large number of natural and anthropogenic objects.

To determine the composition and prevalent plants as well as the presence of open water, we took a summer image. Coniferous and deciduous forests can be clearly distinguished on the image because of different spectral brightness.[6] Light (pine) and dark coniferous forests were separated through analysis of the image by use of "teachers" obtained with the use of a forest inventory plan. Deciduous types (birch, asp) cannot be separated on a summer image.

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For classification of the landscape strata, we selected a key area in the space image. This area is located at the northwest of Tomsk Region and includes the basins of the Elle-Kulunyakh, Katylga, Lontyn-Yakh, and other rivers (Fig. 1).

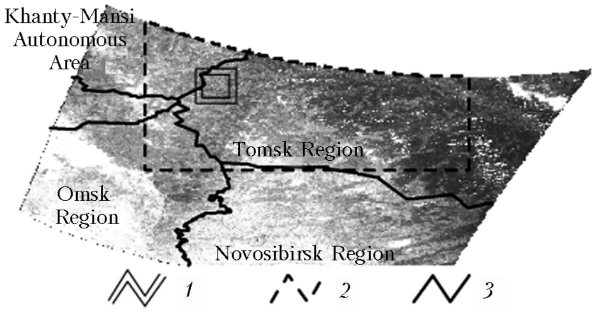

Fig. 1. Space image with boundaries of the key area and the studied scene: boundary of the key area *1*, boundary of the studied scene *2*, region boundaries *3*.

It should be noted that the territory of the key area coincides with the territory of the Vasyugan group of oil fields, which includes the Pervomaiskoe, Katylginskoe, Western-Katylginskoe, Lomovoe, Lotyn-Yakhskoe, and Olenje oil fields in Tomsk Region. In selecting the key area, we took into account its representativeness and coverage of the main typological elements of the territory. The territory of the key area (2653 km^2) covers all types of plant groups, characteristic of Siberian forests and wetlands. The space image was processed with the Erdas Imagine software and then the data were exported into the format supported by the ArcView 3.x GIS, which was used to determine the relative areas of each of the landscape strata.

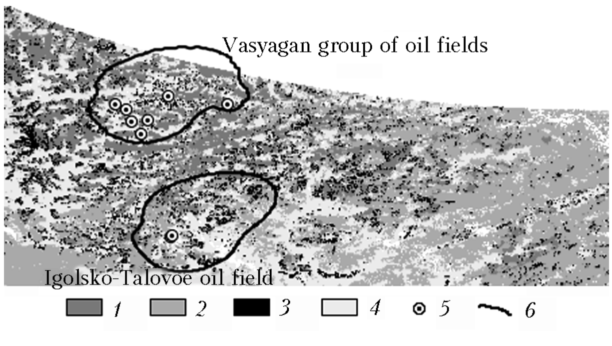

Fig. 2. Map of landscape strata drawn using data of SI processing: dark coniferous forest (*1*), small-leaved forest (*2*), pine forest (*3*), wetland (*4*), flare (*5*), boundary of the polluted zone (*6*).

Figure 2 depicts the map of the landscape structure obtained by processing the space image. In the process of analysis of the landscape structure of the territory, we have determined five types of landscape strata characteristic of the southeastern part of Western Siberia: dark coniferous (fir, Siberian pine), small-leaved (birch, asp) and pine forests, as well as river flood lands and wetlands. The relative areas of landscape strata are tabulated below.

Relative areas of landscape strata in the space image

Area	Type of a landscape stratum		
	Pine forest	Dark coniferous – small-leaved forest	Wetland
Key area	13.39	40.35	46.30
Image scene	10.58	48.76	40.66

2. Methodical issues of evaluation of the atmospheric pollution impact on forests with the use of space images

The GIS approach to evaluation of the atmospheric pollution impact that is described in Ref. 4 and based on combination of the health and landscape-geochemical approaches can be reduced to imposition of the zones of atmospheric pollution with the emissions from stationary sources on the landscape map and determination (using GIS tools) of the areas of landscape strata being under the effect of negative oil production factors.

An important aspect in realization of this approach to evaluation of the environmental impact is determination of the location and size of pollution zones and prediction of the dynamics of their change at the increase (or decrease) in oil production. In our previous papers, (see, for example, Ref. 7) we described the software for determination of the zones of atmospheric pollution based on the use of health standards and simulation of pollutant dispersal in the atmosphere in accordance with the OND-86 technique accepted in Russian ecological practice. The software developed allows one to predict the dynamics of the development of these zones based on the plans of economic development of production enterprises. The experience of using this software showed that it is convenient for computer implementation with application of GIS technologies, which allows the relative area of landscape strata subject to pollution to be determined through overlay superposition of pollution zone contours onto the landscape map using the GIS tools.

To illustrate the practical usage of the approach described, Fig. 3 depicts the simulated zones of atmospheric air pollution with hydrocarbons emitted by petroleum gas flares at Samotlor oil field. These results were obtained using the following parameters: oil production rate of $100 \cdot 10^6$ ton a year, which roughly corresponds to the production level in 1985 (Ref. 8), the burned gas volume of $4.8 \cdot 10^6$ m^3. The calculations were made for different pollution levels determined in fractions of the maximum permissible concentrations (MPC).

Superposition of the simulated zones of atmospheric pollution onto the map of the aerosol concentration[3] demonstrates quite a close agreement of the simulated results with the aerosol anomaly, which can explain the fact that the anomalous aerosol pollution zone near Nizhnevartovsk was formed as a result of oil production in this region of Western Siberia.

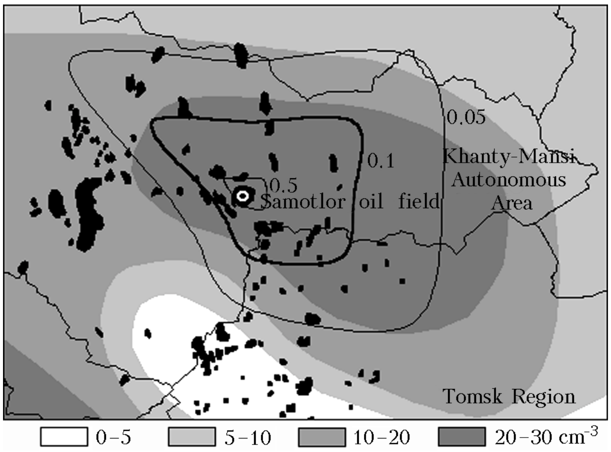

Fig. 3. Map of the distribution of the aerosol particle number density with the superposed zones of pollution from petroleum gas flares of Samotlor oil field.

Below we present the results of application of this approach to prediction of the impact on forests and wetlands. The territory of Tomsk Region incorporates some oil fields belonging to the Vasyugan group of oil fields and the large Igolsko-Talovoe oil field. The oil production region falls in the southern taiga subzone, whose main zonal types are Siberian pine, fir, and silver fir forests characterized by well-developed stands of the second and third growth classes. According to the program of development of the oil and gas producing industry in Tomsk Region for the period till 2005, it is assumed that oil production in the Igolsko-Talovoe oil field will increase by 2005 up to the level of 1 850 000 ton with simultaneous decrease of oil production in oil fields of the Vasyugan group. The prediction obtained taking into account analysis of this scenario is depicted in Fig. 2, which shows the zones of air pollution with soot (according to the prediction for 2005) superimposed onto the decoded and vectorized space image of the studied territory.

The areas of natural strata falling within the zones of atmospheric pollution were determined taking into account the real volumes of soot emissions into the atmosphere from flares on the territory of oil fields. For different pollution levels measured in MPC fractions and for different landscape types, we have calculated the area of a landscape stratum polluted with soot emissions divided by its total area (y) depending on the level of atmospheric pollution and the oil production rate.

Figure 4 depicts the dependence of the relative area (y) of landscape strata polluted with soot on the oil production volume (x). The results were calculated for the territory of Vasyugan group of oil fields and the Igolsko-Talovoe oil field for the pollution level of 0.05 MPC using the space image, whose fragment is shown in Fig. 2.

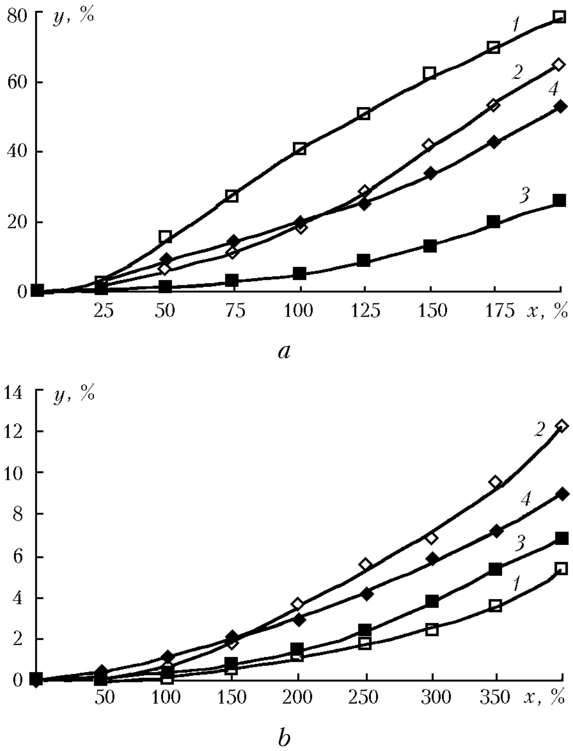

Fig. 4. Relative area of landscape strata contaminated with soot as a function of oil production volume at 0.05 MPC for the Vasyugan group of oil fields (*a*) and Igolsko-Talovoe oil field (*b*); dark coniferous forest (*1*), pine forest (*2*), small-leaved forest (*3*), wetlands (*4*).

Conclusion

The results considered above showed that our realization of the GIS approach to evaluation of the ecological impact of atmospheric pollution using space images allows one to estimate quantitatively the areas of forest and wetland territories subject to the technogenic atmospheric pollution caused by burning of petroleum gas on oil fields. These estimates of the technogenic impact can be used for fast revealing of territories with significant ecological loads on plant ecosystems and for monitoring of changes in the ecological load in time depending on both the oil production level and the types of landscape strata.

The described procedure of processing and decoding of medium-resolution space images, involving the extension of the results of classification of the types of landscape strata revealed on the key area to other fragments of the space image corresponding to hard-to-reach territories of forests and wetlands, allows determination of the landscape structure and the state of forests and wetlands on vast territories.

Acknowledgments

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