REMOTE SENSING AND GIS FOR SPATIAL ANALYSIS OF ANTHROPOGENIC CARBON OXIDE EMISSIONS

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Abstract: Western Siberia hosts one of the main oil-bearing basins in Russia, producing more than 70 % of the country's oil. It is known that oil field flares release carbon oxides into the atmosphere which contribute to the greenhouse effect. This work details the development of a Geographical Information System (GIS) technique which uses satellite image processing to assess the spatial irregularities of anthropogenic carbon oxide emissions. This approach, which tries to make a quantitative assessment of the impact of atmospheric pollution on forest ecosystems, is based on calculating forest ecosystem areas (cells) which are inside atmospheric pollution zones. Particular issues related to the modeling of atmosphere pollution caused by oil field flares are considered. Pollution zones were revealed by standard modeling of contaminant dispersal in the atmosphere. Polluted ecosystem cells were calculated on the basis of oil production volume.

Key words: remote sensing, geographic information systems, GIS, carbon oxides, gas flares, environmental impact assessment, oil field

1. INTRODUCTION

Western Siberia hosts one of the main oil-bearing basins in Russia, producing more than 70 % of the country's oil. Oil reserves in Western Siberia have been estimated to exceed 35 – 40 billion tons, and thus production levels will remain high for at least the next two or three decades. It is known that about half of the gas associated with the produced oil is burnt in flares, with the subsequent release of carbon and nitrogen oxides, hydrocarbons and soot into the atmosphere. Once released the carbon oxides

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contribute to the greenhouse effect, soot blocks the stomas of conifer needles that leads to the drying of forests (especially dark-coniferous ones due to a long cycle of needle replacement), while nitrous oxides form acid precipitation and oxidants in leaves which reduce plant viability (Polishchuk et al., 1999). It is for these reasons linked to atmospheric pollution that Agan forests near the largest Samotlor oil field in Western Siberia are dying.

At present, atmospheric pollution caused by oil field flaring is the main environmental impact of oil production (Fedyunin, 1996; Polishchuk et al., 1999)). Solving the ecological problems created by oil production in western Siberia, perhaps through CO_2 geological sequestration, requires a better understanding of the spatial structure of anthropogenic carbon oxide emissions. A geographic information system (GIS) approach to analysing the spatial structure of carbon oxide emissions is discussed in this paper, extending previous work which assessed the impact of atmospheric pollution on the natural environment (Polishchuk and Tokareva, 2000, Polishchuk et al., 2002). This approach to environmental impact is based on the combination of health and geochemical methods (Polishchuk et al., 2002) for the quantitative estimation of the forest-swamp ecosystems polluted in western-Siberian oil-producing areas. This approach, however, requires ecosystem maps, which are expensive and labour-intensive to produce with traditional methods.

The use of satellite data decreases the costs of producing thematic maps, however their application to assess environmental impact caused by oil production is limited in the scientific literature. In addition the application of GIS and GIS-technologies in combination with satellite imagery to study the effects of pollution on forest-swamp ecosystems is even less common. The application of mid-resolution space images which cover an area of up to 300-350 thousand km^2 is more preferable to research ecosystem structures of large territories.

In this regard, the main purpose of this paper is to address remote sensing and GIS methods as applied to both the spatial analysis of oxide emissions and the assessment of oil production impact on the natural environment in western Siberia. The paper presents some results related to the effects of oil-field flaring on forest-swamp ecosystems in Western Siberia.

As shown in Figure 1, the spatial distribution of atmospheric pollution in Western Siberia is very irregular. One anomalous zone is located near the towns of Nizhnevartovsk and Strezhevoi, caused by gas flaring in the surrounding oil fields. The detailed analysis of this irregular spatial distribution of oxide emission and environmental impact assessment can be carried out using different cartographic and computer modeling techniques, which are described in the following section.

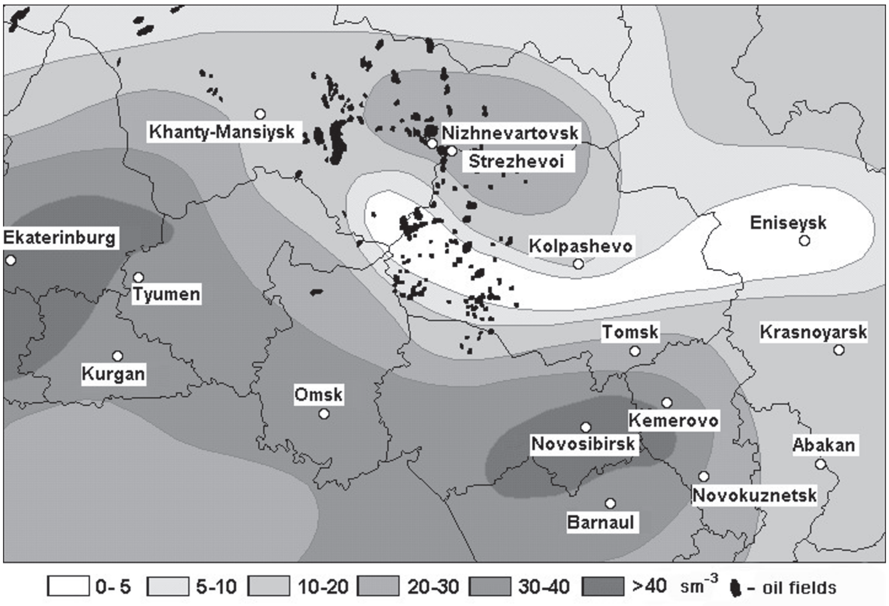

Figure 1. Map of atmospheric pollution distribution in western Siberia

2. GIS MODELLING

Typically environmental assessment is based on the application of health and safety rules, even if they are not adapted to ecosystem and ecosystem biodiversity. Instead one of the best approaches to assess the impact of chemical pollution on vegetation biosystems is to determine the areal distribution and size of polluted ecosystem complexes. That is why the complex approach (Polishchuk and Tokareva, 2000; Polishchuk et al., 2002) to environmental impact assessment used in this paper is based on the combination of health and geochemical methods. Such an approach, however, requires large volumes of environmental and remote sensing data on the anthropogenically-impacted areas, data which cannot be processed without the use of GIS and GIS-technologies. Application of GIS tools, which permit multidimensional data analysis, simplifies the procedure of ecosystem forecasting and environmental impact assessment of carbon oxides and other gas contaminants.

The general structure of the Geo-Information Modeling System (GIMS), given in Figure 2, consists of the following units. “Database” includes environmental and other quantitative information about the study area. The ”Digital map subsystem” hosts the area maps, including a 1:1,000,000 scale digital map which forms the basis of the subsystem as well as other topographical maps of other scales and different thematic digital maps. The "Modeling subsystem" is the most dynamic part of the GIMS, as it is used to calculate atmospheric contaminant concentrations in order to identify the spatial distribution of atmospheric pollution.

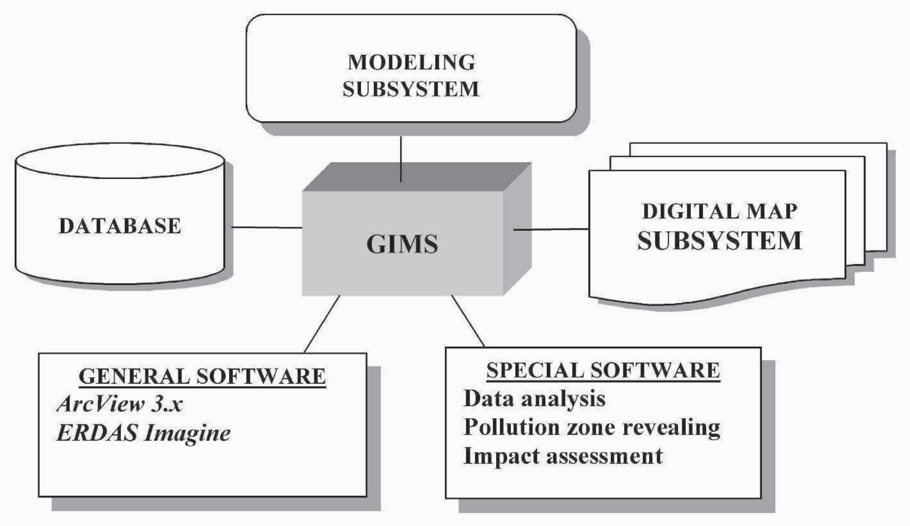

Figure 2. General structure of the geo-information modeling system.

As is shown in Figure 2 "General software" consist of the GIS software ArcView 3.x and ERDAS Imagine, while "Special software" consists of various components to assess the impact of atmospheric pollution on the ecosystem. One of the main components are program tools to identify pollution zones by analysing modeling data from the "Modeling subsystem" and to identify multiyear-averaged pollution zones. Air pollution zones (Polishchuk and Tokareva, 2000) are determined for different pollutant concentrations by modeling the pollutant dispersal in the atmosphere.

Another component of "Special software" is a computer program which assesses impact. By overlaying pollution-zone outlines on the ecosystem map it was possible to calculate the areas of the polluted complexes using GIS tools. This code, developed with the program language Avenue, calculates the relative areas of ecosystem types occurring in a pollution zone. The program consists of some standard functions and is activated directly within the ArcView interface. The user must first active the thematic layer containing the pollution zone of interest and then start the calculation of the relative areas. The layers containing ecosystem types for which the user wants to make calculations will be accommodated in the list of the program.

The program calculates the area of every ecosystem type occurring in a pollution zone, and then determines the its percentage relative to the full ecosystem type area or the area of a satellite image. Calculation results are represented graphically on the monitor screen, while the final impact assessment results regard the analysis of polluted ecosystem areas normalized to area. Clearly these relative areas will depend on the concentration of the pollutants and the volume of the oil produced. The results of this study are given below in the next sections.

3. SATELLITE IMAGE PROCESSING AND MODELING OF POLLUTION ZONES

Satellite images are widely applied to the study of environmental status. High and middle resolution images obtained from the Russian satellite Resource–O1 were used in this paper. Satellite image processing involves the following procedures:

1. Validation of remote sensing data.
2. Classification and interpretation.
3. Vectorization.
4. Thematic layer formation.

Ecosystem maps, forest-use plans and field data may all be used for validation and classification. All basic forest-swamp ecosystem types are represented within the pilot study territory (PT). The 1:1,000,000 scale digital map was used as a topographic base map for the GIS. The middle resolution satellite image classification was performed using ERDAS Imagine software and forest-use maps as a classification scheme of the pilot study territory. Classification results of the PT ecosystem types were then moved to the entire studied area in the satellite image, which below will be referred to as a “scene”. A fragment of a three-zone satellite image (spatial resolution = 140 m) from the Russian satellite “Resource - O1” (scanner MSU-SK) was used as the scene. Image vectorization was performed using ERDAS Imagine and then vectorized data were exported to a GIS ArcView format. The relative areas of each ecosystem type were determined using the vectorized satellite image. The ratio of the areas of various vegetation types characterize the ecosystem structure of the territory.

As mentioned above, the pollutant impact assessment is based on the definition of the pollution zones and their subsequent plotting on the computer map or satellite image. To identify the pollution zones it is necessary to model pollutant distribution in the atmosphere. Nowadays there are many different models of air-chemical dispersion. The present work has applied the OND-86 method, which is the most commonly used approach in Russian environmental articles. It allows for the user to calculate chemical concentrations at any point in the study area using the distance from the emission source, year-averaged volume of emitted gas and average local meteorological conditions. Modeling of air pollutant dispersal consists of the following steps:

1. Determination of the locations of pollution sources using GIS and computer maps. GIS allows a user to make spatial selections of map objects and thus one can select pollution sources in the study area.
2. Input sources and chemical properties from the "Database". The user interface allows one to construct queries to the "Database" using dialog forms and properties of selected air pollution sources and chemicals.
3. Calculation of chemical concentrations using the air pollutant dispersal model.

Issues regarding the outlining of pollution zones were considered in previous papers (Polishchuk and Tokareva, 2000; Polishchuk et al., 2002). In summary this work involves the following steps:

1. Air pollution dispersion modeling.
2. Determination of pollution zone boundaries.
3. Visualisation of the pollution zones.

To outline the pollution zones it is necessary to determine chemical concentrations throughout the study area. This is accomplished by dividing the region into a spatial grid consisting of individual cells, the size of which depends on the map representation scale. Every considered air pollution source and chemical are accounted for via dispersal simulation in every cell. The next step is to determine the boundaries of the areas, while the final step involves the plotting of these boundaries on the computer map or satellite image using GIS tools, as is shown in Figure 3.

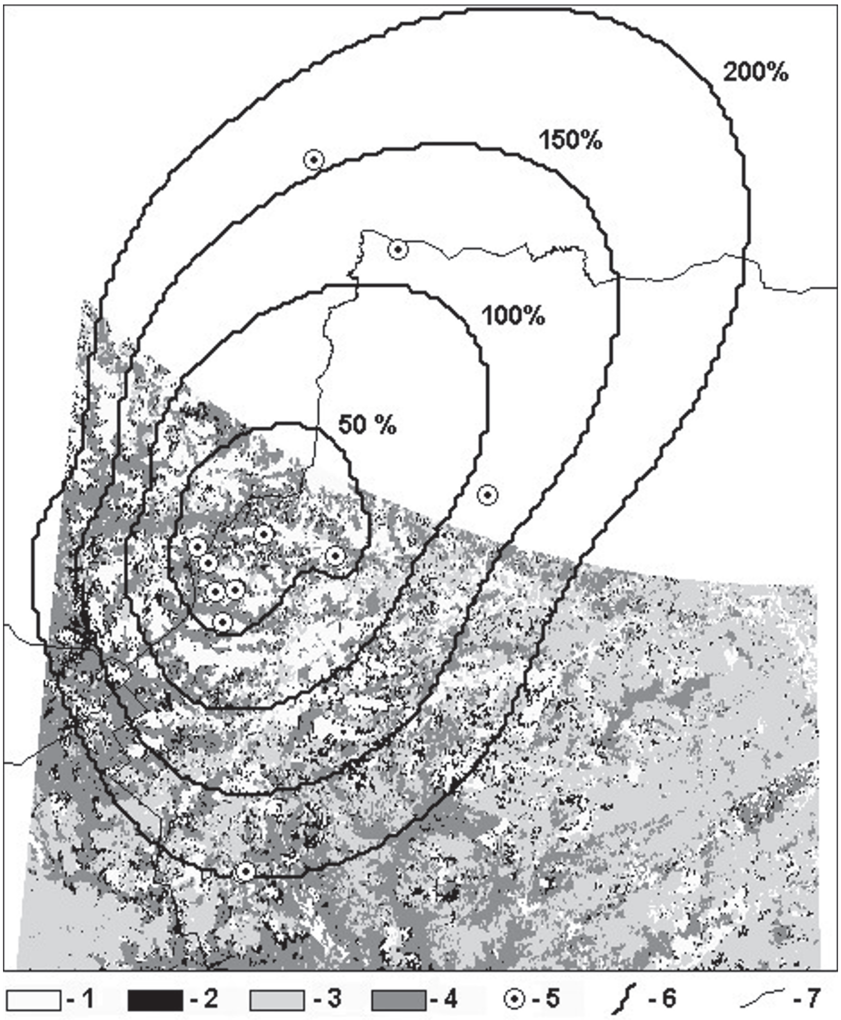

Figure 3. Ecosystem-type map after image processing. 1 – dark-coniferous forest, 2 – pine forest, 3 – small-leaved forest, 4 – swamp, 5 – gas flare, 6 – air pollution zone, 7 – oil fields.

4. IMPACT ASSESSMENT OF CARBON OXIDE EMISSIONS ON SIBERIAN FORESTS

The results of an environmental impact assessment obtained on the basis of satellite images are presented below. First a digital map of the natural ecosystem structure was constructed, and then the size of the various polluted ecosystem types (normalized to the area of corresponding ecosystem type) were calculated. These relative areas depend on both the pollution level and the volume of oil production, to which the volume of burnt accompanying gas is connected. The dependency of the relative areas of polluted ecosystems on the volume of oil production, calculated for fixed levels of air pollution by carbon oxide emissions, are represented in Figure 4. Results of the calculations for oil fields of the Vasugan group, under concentration, are $0{,}3 \cdot 10^{-3}$ mg/m^3.

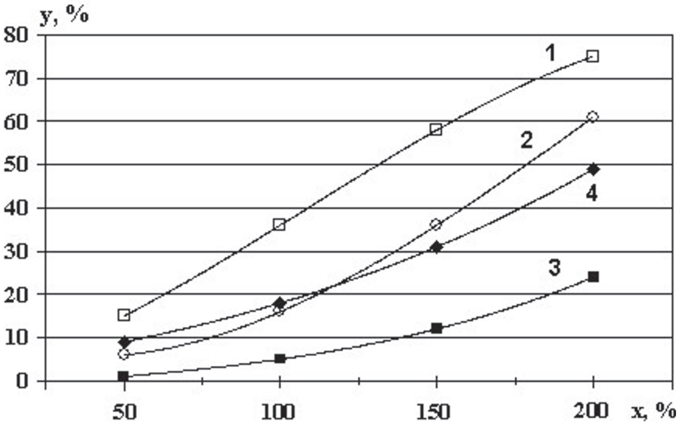

Figure 4. Relative areas of polluted vegetation types, depending on the volume of oil production at the Vasugan oil field. 1 – dark-coniferous forest, 2 – pine forest, 3 – small-leaved forest, 4 – swamp.

5. CONCLUSIONS

Study results have shown that the geo-information approach to assess ecological impact caused by chemical atmospheric pollution using remote sensing data allows the objective definition of areas having significant ecological loads on specific ecosystems. The described procedures, involving satellite image processing, makes it possible to transfer the results from the classification of one satellite image section onto other sections of a satellite image showing regions which are difficult to access. Such an approach allows the analysis of various vegetation types and ecosystems over large territories using satellite imagery. This approach may be used to carry out regular monitoring of changes in the ecological load, both depending on oil recovery levels and ecosystem types. The paper demonstrates the opportunity to study the spatial distribution of anthropogenic carbon oxide emissions and to assess its environmental impact.

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