Cumulative Environmental Impact Assessment of Oil Production Using Space Imagery Products

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Issues related to oil and gas production impact on environment are presently becoming of special importance for companies operating in oil and gas industry, and to a great extent this is due to the authorities and society focusing on ecological issues. Ecological issues in particular become a noticeable and sometimes key argument in property-based disputes regarding the rights for developing certain fields. Oil and gas producing companies are facing the following objectives:

- prompt assessment of actual environmental impact of applied technology;
- differentiation of impact resulting from company's own activities and that inherited from previous field owners (especially applicable to the fields developed back in the Soviet times and taken over by new owners in 90's – early 2000's);
- setting of priorities and optimization of the contaminated and damaged lands reclamation process;
- selection of optimal processes and partners for developing new fields;
- main pipeline routes planning taking into account their impact on environment.

In 2006 "Transparent World" non-profit partnership together with their American partners, World Resources Institute and TNK-BP company commenced implementation of the Project called "Cumulative Environmental Impact Assessment of Oil and Gas Production in Russia".

Specifics of the project are as follows:

- use of open information only. We aim at developing methods of measuring impact on environment that would not require receiving materials and permissions from field developers as well as use of corporate confidential information or restricted information;
- mandatory requirement of approving results by competent experts. Under the project the expert council was formed and has been functioning, comprising specialists of various disciplines, and representatives of scientific and public institutions. All publications regarding results of the project will go through preliminary and mandatory review of independent experts;
- the project is joined by independent ecological public organizations such as Russian Branch of the Wild World Fund (WWF), Greenpeace Russia, International Social Ecological Union;
- the project is tailored for three years. During the first year we dealt with working out a technique using pilot areas as examples: Pokrov field in Orenburg Oblast and the Samotlor field in Khanty-Mansi Autonomous Area (Yugre);
- TNK-BP Company provides financial support and ensures access of the project participants to its fields, selected as the pilot areas.

Source Data

Due to the abovementioned specifics space imagery data in particular are the primary data source for assessing the impact. We used the following types of images:

- Landsat 7 ETM+ in 1999 – 2002 – 6 spectral channels with 30 meter resolution, 1 panchromatic channel with 15 meter resolution and 2 TIR channels with 60 meter resolution;
- Landsat 5 TM in 1988 – 1993 – 6 spectral channels with 30 meter resolution and 2 TIR channels with 120 meter resolution;
- Terra ASTER in 2002 – 2005 – 3 spectral channels with 15 meter resolution and 1 TIR channel with 90 meter resolution.

The above data are open to the public. The Landsat images before 2001 – 2002 are for free downloading from the University of Maryland website. The ASTER images were also free until recently. Although charges have been introduced for those images the price is quite affordable even for non-profit organizations.

At the same time all above images cover only the period before 2001 – 2002 with exception of some later Aster scenes. When using those we can assess the impact as of the beginning of the century. Up-to-date assessment requires relevant images. The image source for the project is ScanEx Research and Development Center, which receives various space data at its own station network covering the entire Russian territory. In particular we used the following types of images:

- SPOT 2/4 HRV/HRVIR in 2006 - 4 spectral channels with 20 meter resolution and one panchromatic channel with 10 meter resolution;
- IRS-1C/1D LISS-3/PAN in 2005 – 2006 - 3 spectral channels with 23 meter resolution and one panchromatic channel with 5.8 meter resolution;
- EROS in 2005 – 2006 – panchromatic images with resolution of around 2 meters;
- RADARSAT-1 in 2004 – 2006 – radar images with standard mode resolution of 25 meters.

Landsat 5 TM images received at the stations owned by RDC ScanEx are also rendered as promising for future use.

The main outcome of the project first year per the pilot areas

Using presently available space images during the pilot phase of the project we managed to single out the following categories of areas/facilities, emerged as a result of oil field development:

1. Areas with initial ecosystems entirely destroyed through construction of infrastructure facilities:

- well pads;
- individual drilling sites/wells (predominantly exploration wells);
- roads;
- pipeline routes/overhead power lines;
- flare facilities;
- borrow pits and sand stockpiles (as a result of wash-in);
- industrial sites (pump stations, etc);
- residential areas;

- abandoned infrastructure facilities with recovering secondary forest vegetation.

Interpretability of these infrastructure facilities turned out to vary for different pilot areas. Thus in case of the Samotlor field (and apparently for the majority of other Western Siberian fields) all infrastructure facilities possess quite sharp interpretation signatures and are easily detected even on medium resolution images, such as of Landsat. Comparison with TNK-BP data showed that they almost fully matched the data produced through processing of space images. Certain difficulties come up only when singling out pipeline routes, overhead power line routes and unimproved roads at congested locations.

Use of 15-30 meter resolution images for the above areas allows mapping infrastructure facilities with accuracy corresponding to 1:100,000 – 1:200,000 scales. Use of IRS PAN panchromatic images with 5.8 meter resolution allows achieving adequate accuracy for drawing 1:25,000 scale maps and could be more attractive in price versus alternative aerial photographic survey.

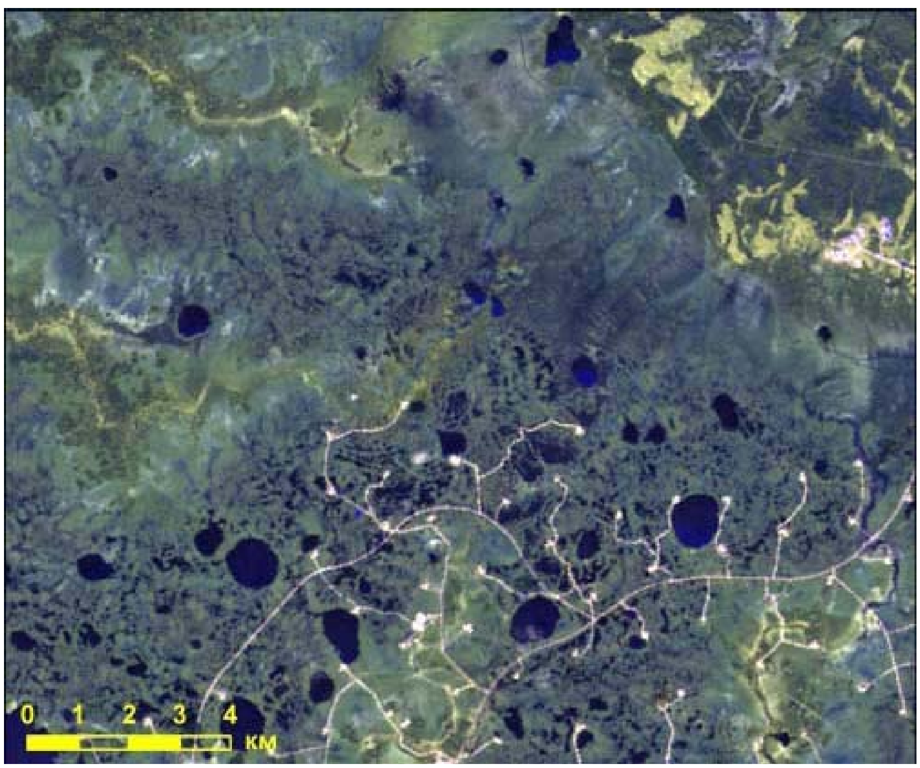

Fig. 1 Landsat-5 TM image. Spatial resolution: 30 meters. Imagery date: May 22, 1988.

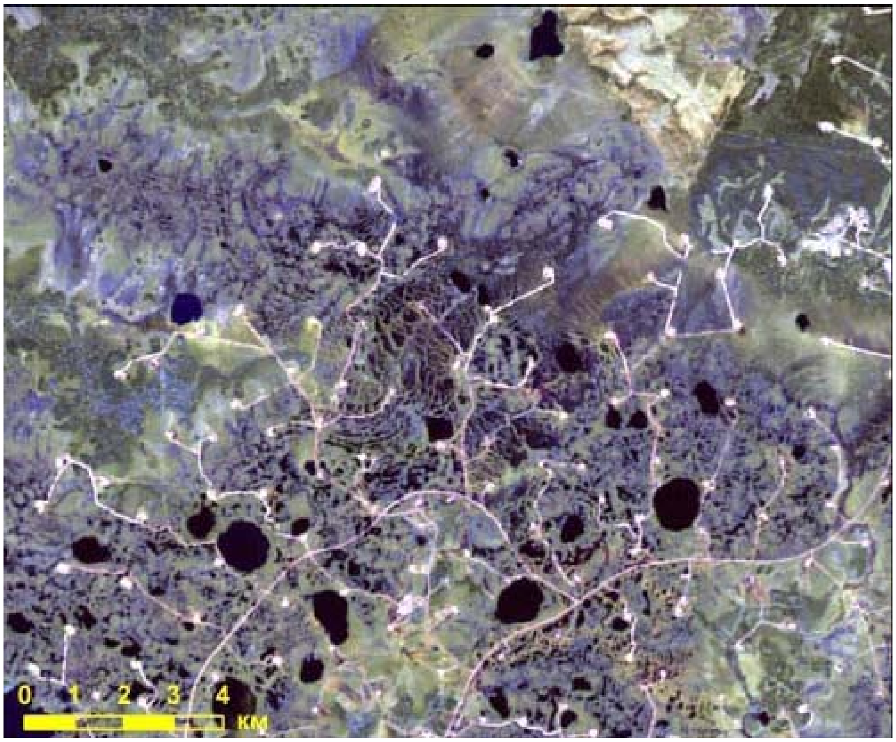

Fig. 2 Landsat-7 ETM+ image. Spatial resolution: 30 meters. Imagery date: September 19, 1999.

Fig. 3 Image of SPOT-4 CNES, SpotImage, RDC ScanEx. Spatial resolution: 20 meters. Imagery date: June 1, 2006

A lot more difficulties arise from working with fields located in long developed regions. Here the infrastructure of oil and gas industry is masked by other types of anthropogenic impacts (for instance, impact of agriculture, general use infrastructure, infrastructure of other industries). Thus, when working with the area of the Pokrov field in Orenburg Oblast the reliability of detecting well pads on Landsat, ASTER, IRS LISS and IRS PAN images accounted for 50%. Only use of EROS images with approximately 2 meter resolution allowed reliable detection of those infrastructure elements.

Fig. 3 The Pokrov field. EROS-A image. ImageSat International N.V., RDC ScanEx, 2005. Spatial resolution: 2 meters. Imagery date: November 7, 2005. Scale: 1:20,000.

2. Areas with original ecosystems destroyed or changed as a result of contamination/ eutrophication:

- quite large (larger than 1 ha) areas of oil contamination after old and recent spills as well as areas immediately after reclamation (the latter with peaty soils are very much like the contaminated areas prior to start of vegetation recovery);
- secondary euthrophic vegetation in areas of old and moderate oil contamination, in marginal areas of oil contaminated territories. (As a rule this allows more precise detection of actual boundaries of oil contamination);
- areas of early oil contamination, where secondary vegetation sprang as a result of reclamation or natural recovery;

- in a number of cases but with lower degree of reliability it is also possible to detect areas with modified vegetation as a result of relatively low euthrophication due to various reasons (without oil contamination continuum or euthrophied not as a result of spills at all, often on-site survey does not reveal traces of oil products).

The primary interpretation signature of areas with heavy oil products contamination not covered with vegetation is glowing in far infrared (thermal) band. In visible, near and medium infrared bands dark oil crust looks the same as water – it absorbs most of the emission but at the same time it is considerably warmer. Pre-detection of these areas was achieved by semi-automatic classification using Kohonen neural networks (ScanEx NeRIS software product). Comparison with the company own data on the Samotlor field and random field inspection confirmed reliability of this method. Some contaminated areas were even detected, which weren't originally marked up in the company database.

A certain problem is presented by unavailability of up-to-date satellite data in thermal channels with sufficient resolution. After virtual failure of Landsat 7 satellite in 2003 the best resolution (90 meters) is provided by Aster images. However efficiency of this tool is low and full coverage of large areas could be received only within several years. More or less up-to-date information can be received from still functioning Landsat 5 satellite; however, its thermal channels feature quite low resolution (120 meters). For the next few years use of radar images represents quite a promising solution, as they are quite sensitive to surface moistening and easily differentiate between water-covered areas and relatively dry areas. An alternative option to this could be the use of defective images still coming from Landsat 7 satellite. The U. S. Geological Survey (USGS) continues distribution of such images at a low price. It is even suggested that these data will become shareware. Although some 22% of information is missing on those images, use of multiple scenes may help in achieving quite full coverage of the area being surveyed.

At the same time considerable portion of heavily contaminated area surface is not solidly covered with oil crust and topped with secondary vegetation. This fact doesn't allow detecting such areas with the method outlined above. However, the secondary vegetation itself represents an excellent indicator of contamination since it's a lot different from the primary vegetation being characteristic of the oil-producing areas of the Western Siberia. Due to presence of traces of oil products glowing of these areas is also registered in the thermal band but less bright than that of areas not covered with vegetation. However, based on our observations these are the certain types of secondary vegetation (predominantly cattails) that indicate actual boundaries of a spill.

To draw these boundaries more precise visual interpretation was performed using multispectral images. The best results were obtained with the use of Aster images, that allowed drawing spill boundaries more precisely than Landsat or SPOT images. Newer SPOT and IRS LISS images were used to verify up-to-date situation.

Preliminary comparison of these results with the company own data showed sufficient degree of matching but also revealed certain variations in contaminated areas boundary contours. From our standpoint these variations are related to the variations in applied criteria. The company database was built on the basis of ground assessment of land contamination with oil products. With that, low concentrations of contaminants as well as areas predominantly contaminated with mineral elements as a result of water-oil mixture spills could be disregarded. Our methodology first of all reveals a result of the impact – changes to vegetation, which could be longer than presence of oil products in soil. Presently obtained results have been forwarded to TNK-BP for more thorough review.

Visual interpretation can also allow detecting areas where vegetation was changed earlier but traces of oil products ceased to exist. As a rule such areas differ from contaminated areas from the standpoint of vegetation. Additional interpretation signatures are often presented by diffused boundaries of these areas, their flow-like shape contours, their confinedness to water passages and shallows, indicating that some liquid flowing down the slope has a negative impact on the vegetation cover.

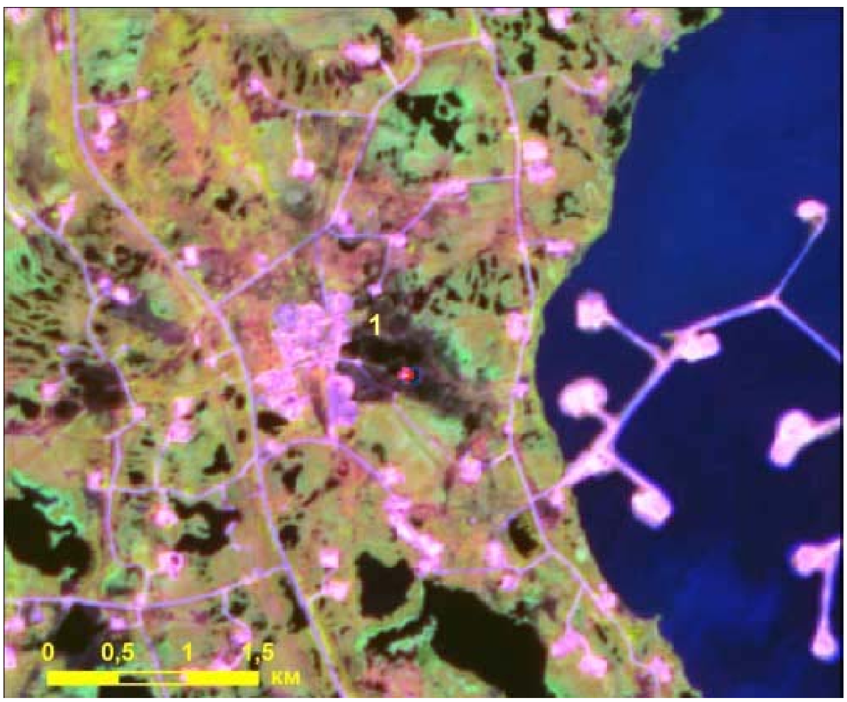

Fig. 5-A. The Samotlor field. Terra/Aster image. Spatial resolution: 15 meters. Date of imagery: July 2, 2002. Scale: 1:50,000.The area contaminated with oil products. Number 1 shows contamination masked by secondary vegetation.

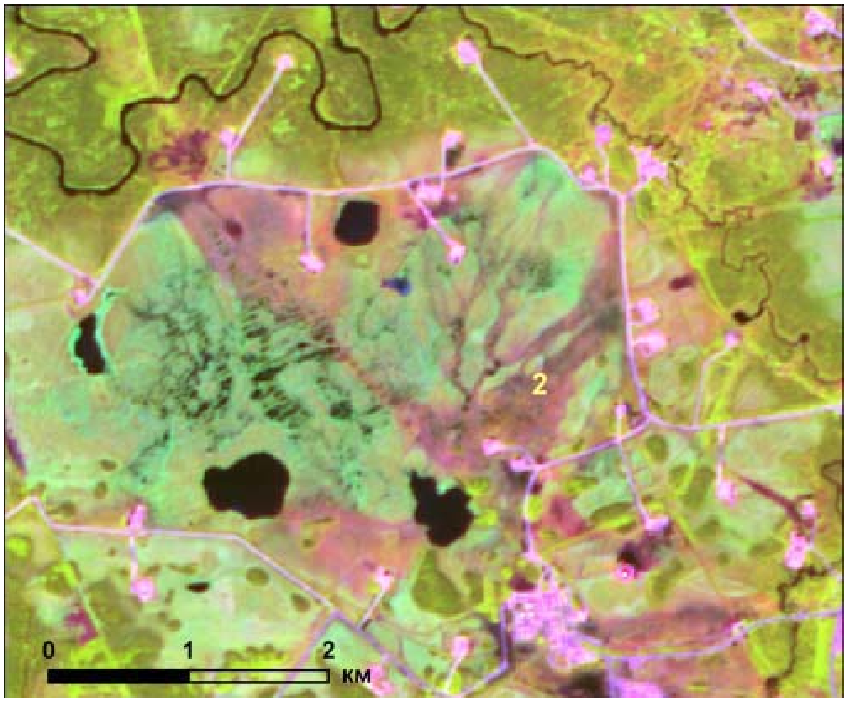

Fig. 5-A. The Samotlor field. Terra/Aster image. Spatial resolution: 15 meters. Date of imagery: July 2, 2002. Scale: 1:50,000.The area with vegetation changed as a result of old or low intensity contamination (shown by number 2).

The reason of degrading vegetation pertaining to these areas in the conditions of the Samotlor field most frequently appeared to be old or low intensity spills. However in a number of cases one could also suggest anthropogenic euthrophication due to other reasons: changes in hydrologic behavior, ingress of mineral materials during construction, etc.

For the conditions of the Pokrov field in Orenburg Oblast the only detected areaas of contamination were slurry pits. This fact doesn't indicate complete absence of spills in this field but bears evidence of their small size and short existence. The information received from the company representatives supports these assumptions. In conditions of quite densely populated area, agricultural landscape and easier access to the area for ecological monitoring the majority of spills are detected and eliminated within the first few hours. Also it is needless to say about changed vegetation in conditions of solid agricultural reclaiming. Initial vegetation here has been long and almost fully replaced with man-made vegetation in the fields or weed vegetation along field and road margins. Spill-based euthrophication to our viewpoint doesn't change much in the overall picture of anthropogenic impact.

3. Sea areas, whose ecosystems are disturbed as a result of contamination:
   - contamination of water reservoirs with suspended solids (increased opacity) as a result of hydraulic wash-in.

4. Areas that have been exposed to indirect impacts.
   - areas run through by forest fires,
   - clear cuts.

When speaking about oil and gas production affecting environment, multiple indirect impacts are usually disregarded although in their extent they often exceed direct impacts. Thus clear cuts resulting from forestry development in the area of the Samotlor field may seem to be unrelated to the oil production. However the mere existence of transport infrastructure emerged as a result of oil fields development made forestry economical in this area.

Analysis of old space images also suggests correlation in time and space of the beginning of the oil field development with large forest fires that took place in the environs.
Under this project we also try to detect and map all similar anthropogenic impacts in the oil and gas producing areas of the Western Siberia in some or other way connected to oil and gas production in the region.

Few conclusions on the results of the first stage of the project

Oil field infrastructure is detected quite well using space images. For the primary oil and gas producing areas of the Western Siberia where oil and gas production is virtually the only type of anthropogenic impact, infrastructure mapping and existing map updates can be carried out on the basis of affordable space images (Landsat, SPOT and IRS) scaled up to 1:25,000. For agriculturally developed areas more expensive high resolution images shall be used, which however could be rendered as an alternative to aerial photographic survey and they are not considered as confidential.

Use of remote methods allows rather reliable detection of area boundaries with oil product contamination including those in the Western Siberia conditions –with secondary vegetation cover.

Methods that we use also allow assessing success of reclamation of contaminated areas. Though newly reclaimed areas don’t differ much from contaminated ones on space images, in a few years reclamation success will be possible to assess by the degree of vegetation in the reclaimed areas.

Many old contaminated areas are successfully overgrown by secondary vegetation. To our opinion their reclamation is unpractical since it only slows down instead of speeding up the process of natural succession.

When assessing environmental impact of oil and gas production it’s also important to keep in mind indirect types of impact, which do not directly result from oil field development but wouldn’t be possible in other conditions.