D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

SATELLITE AND AIRBORNE REMOTE SENSING DATA FOR MONITORING OF AN OPEN-CAST MINE

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ABSTRACT

In this study, the problem of environmental monitoring and land-use/land-cover changes over the lignite open-cast mine and power plant area, was investigated. For this purpose the LANDSAT TM and SPOT (P+XS) imageries as well as airborne photography have been used. The study site was the Belchatow Mining Energy Complex (BMEC) which has been in operation for more them 25 years. An affordable method had to be devised to detect, assess and measure the environmental remediation programs.
BMEC is a major energy source for the central part of Poland. Located about 200 km South-West of the Warsaw it contains a large open-pit mine with the 350 m high dump body and electric power plant. The lignite deposit is 55 m thick and lies 150 to 250 m below the surface.
The main objective of this study was to demonstrate the potential of SPOT and LANDSAT products and image processing techniques for mapping of environmental impacts caused by BMEC long-term activity. And also to analyze their ability for making rapid classification of multitemporal satellite data for the timing and spatial changes detection. A variety of standard image processing routines were run on the satellite data set like preprocessing and image enhancement, unsupervised and supervised classifications, merging of SPOT, LANDSAT and airborne imageries, image transforms and filtering techniques.
For analysis and interpretation, the cartographic data sets were digitized and merged with the satellite imageries for content enhancement and spatial comparison. The processed images were viewed and visually analyzed in a GIS environment.
The results of the study show that multispectral LANDSAT TM and panchromatic SPOT imageries are very useful and economically attractive for conducting environmental inventories, monitoring and mapping in an open-pit mine area. This allowed the investigators to obtain very important thematic information about the land-cover categorization, landscape changes, forest degradations, detection of the types of vegetation cover and evaluation of the reclamations activity on the overburden dumping areas. Combining SPOT panchromatic and LANDSAT TM multispectral imagery was the most cost-effective and efficient way monitor the mining-energy complex and its surroundings. And it should be strongly recommended even for the detailed studies over the relatively small areas. This is the most significant practical success of the study presented.

1. BACKGROUND

Since the first launch of the first SPOT satellite the view of the Earth's surface have been significantly focused of the high (10 x 10 m) resolution of the SPOT-panchromatic band. The SPOT imageries have been tremendously useful tool in the survey, management, monitoring and mapping even the relatively small areas.
In this study, the problem of environmental monitoring and mapping change over the mining and power plant area was investigated. It is a simple illustration of the SPOT-View product thematic interpretation possibility.
In Poland, development of the energetic complex based on the coal as well as lignite resources utilization. The Belchatów Mining Energy Complex (BMEC) being investigated, is located in the Middle Poland, 6.5 km south the City of Lódz. The BMEC consists of two parts: lignite open-pit mine with the dump body (350 m in high) and electric power plant (Fig. 1). There is a mining over 30% of the lignite production in Poland, and electric plant gives of 10% of the country electric energy amount.
The deposit body of 55 m thick, occurs 150-250 m beneath the ground level and spreading out of 3 by 25 km parallel to the latitude (E-W).
The environmental impacts have been started over 25 years ago, since initial works, particularly under-ground water drainage system have been turned on. The next step of the environmental degradation process appeared 10 years after, when the electric power plant has been started with the gasses and dustfall emission. The view

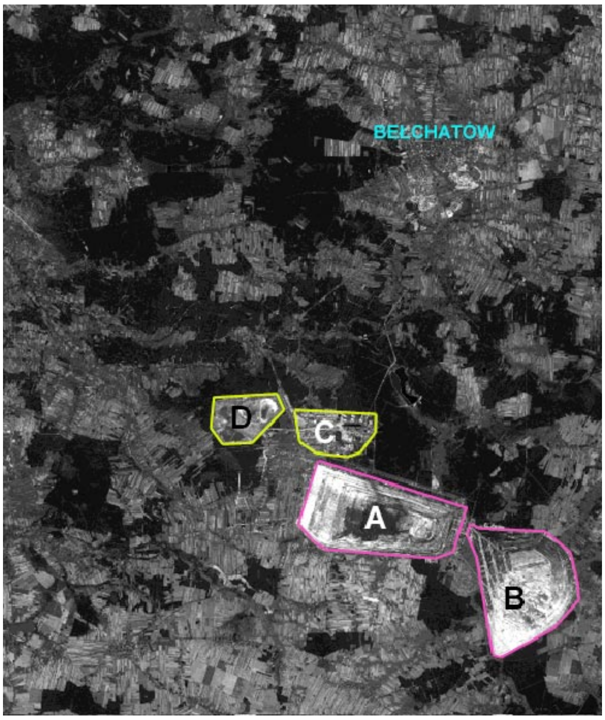

Fig. 1. SPOT PAN image over the study area (A - open-pit-mine; B - dump area; C - electric power plant complex; D – slag&ashes containers)

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from space by SPOT-HRV and LANDSAT TM sensors seems to be the best way to discriminate, assess and even to measure these destructive phenomena (Mularz S. C., 1996).

2. STUDY AREA AND DATA

The study site was approximately 28 by 24 km rectangular surface located in the central part of Poland about 200 km South-West from Warsaw.

The study area has to be limited to the size of SPOT-View product being prepared by the SPOT-IMAGE for the purpose of this project. It covers the only one fourth (N-W) of the area which we have planed to use for this investigation. There was no possible also to get (P+XS) SPOT scene, for this particular area.

Thus, the main goal and thematic range of the project has to be reoriented. Instead of assessment of the environmental impacts by BMEC activity, in regional scale, the local aspect of the environmental monitoring and mapping over the mining surface, particularly on the dump area, will be presented.

Finally, the following set of data have been used:

1) SPOT-View[R] Basic Precision 15' x 15' panchromatic image, acquired on 29 August 1990, kindly delivered by SPOT_IMAGE;
2) SPOT XS multispectral image, acquired on 14 May 1986 by SPOT1; geometric processing level-1B (Courtesy by IGiK, Warsaw, Poland);
3) LANDSAT TM imagery acquired on 12 June 1996;
4) color airborne photography taken on 30 May 1996 within the PHARE program;
5) Set of cartographic data, such as:
   a) topographic maps (scale: 1:200000, 1:50000);
   b) forest degradation inventory map based on interpretation of the color infrared aerial photographs on August 1985 (scale: 1:25000);
   c) inventory map of vegetation cover on the overburden dump area (scale: 1:8500); the map was compiled on the base of photointerpretation of the black and white aerial photographs, on 4 July 1987;
6) reports of reclamation activity on the dump area contained the conceptual studies and experimental field works, results of the ground inventory etc.

Because the SPOT XS image was covering only South-Eastern part of SPOT PAN image, a sub-study area was derived, as an overlay of SPOT XS image. This was for the detailed studies separated, especially for reclamation activity assessment on the external dump body (Fig. 1).

3. OBJECTIVES AND APPROACH

The basic objective of this study was to demonstrate the potential of the SPOT/LANDSAT products and image processing techniques for space mapping of environmental impacts connected with the Belchatów Mining-Energy Complex long-term activity. And also to analyze their ability for making rapid coarse land-use classification of the multitemporal satellite data for timing and spatial changes detection.

Until now several methods have been developed in order to combined SPOT panchromatic (P) with XS or LANDSAT TM bands (Carper *at al*, 1990; Chavez, 1986; Cliche *at al*, 1985; Gillespie, 1980; Gillespie *at al*, 1986; Cochrane, Lasselin, 1991; Durand, Lasselin, 1992).

As the first step a resampling procedure is always necessary to obtain the same scale for both multispectral (SPOT XS, LANDSAT TM) and panchromatic (SPOT PAN) channels.

Resampling methods need interpolations and radiometric approximations: bilinear, bicubic or nearest neighbor.

In this study the following methods have been tested, which are based on:

- substitution of a SPOT XS or LANDSAT TM band for SPOT panchromatic channel;
- integration of the SPOT PAN band into the multispectral channels;
- IHS (Intensity, Hue, Saturation) transformation;
- SPOT IMAGE's product (P+XS).

The interesting results for a visual interpretation was obtained by replacing one of the bands from the visible part of the electromagnetic spectrum (XS2/TM3 or XS1/TM2) for the SPOT panchromatic channel. However, colored disturbances appeared because of both viewing SPOT PAN and LANDSAT TM imageries were far from each other.

For integration of the SPOT PAN band into the multispectral channels, the Jaakkola method was used (Durand, Lasselin, 1991). This method supposed that the loss of geometric features fpr a multispectral images (SPOT XS or LANDSAT TM) with regard to the SPOT panchromatic image can be estimated by comparing a PAN image (10 m resolution) to a 20 or 30 m degraded images for SPOT and LANDSAT TM system respectively:

$$PXS = XS*(P10/P20)$$

$$PTM = TM*(P10/P30)$$

The transformation RGB to IHS allows the separation of the space information (intensity) and the spectral information (hue, saturation). Therefore it is possible to replace the intensity by the SPOT panchromatic band, and compute the inverse transformation PHS to RGB (Carper *at al.*, 1990). Moreover, this method can be used also in PCA (Principal Component Analysis) by substitution of the intensity for the first or second component.

Based on the high resolution of SPOT-panchromatic image (10 x 10 m) very detailed interpretation studies of natural phenomena as well as man-made objects, were also investigated.

The first approach used was one of simple temporal comparison. Land cover classification maps derived from SPOT XS and P data, acquired at different times were digitally compared to detect the temporal land-cover changes over the BMEC area (Fig. 2).

For further analysis and interpretation the remotely sensed and cartographic data sets were digitized, geometrically rectified, preprocessed and merged for information content enhancement and spatial comparison.

Particularly, integration of then P channel into the multispectral XS channels was done using the following formulas (Durand, Lasselin, 1991):

$$R_{PXS1} = \frac{2P * XS1}{XS1 + XS2}$$

$$R_{PXS2} = \frac{2P * XS2}{XS1 + XS2}$$

where:

R_{PXs1} – final radiometry of the 10 m pixel from the band XS1;

R_{PXS2} – final radiometry of the 10 m pixel from the

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band XS2;
P – radiometry of the panchromatic channel;
XS1, XS2 – radiometry of the 20 m rectificated pixel from channel 1 and 2; respectively.

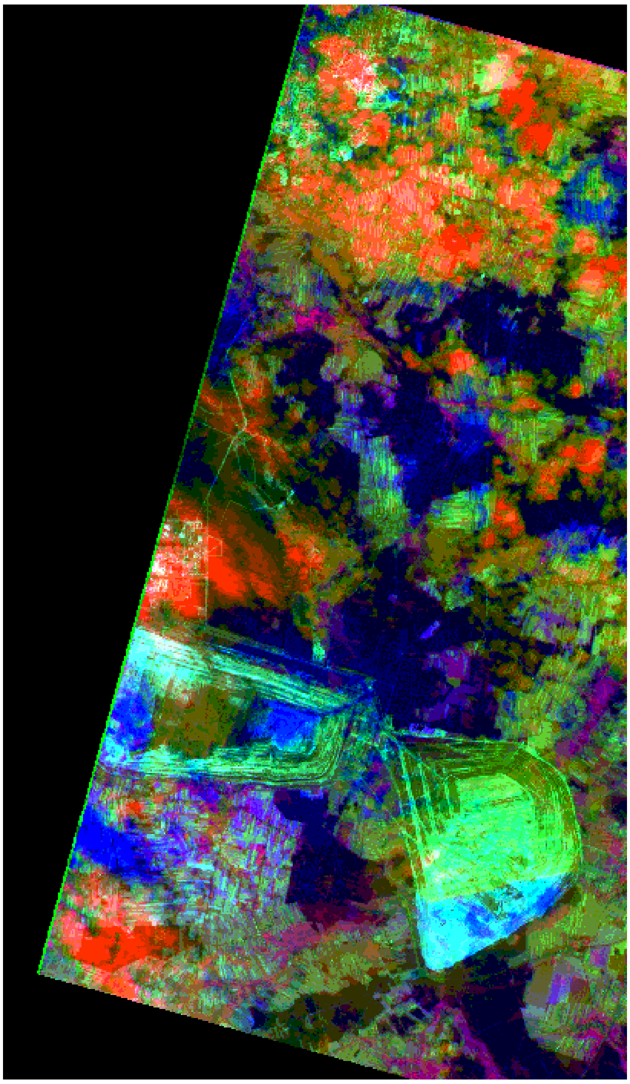

Fig. 2. False colour composite (RGB) forom SPOT (XT) after merging with SPOT (P). Time differences are visible.

A set of the image processing procedure of the SPOT and LANDSAT TM data have been used for:
1) land-cover categorization;
2) the landscape changes;
3) forest degradation;
4) detection of the types of vegetation cover and evaluation of the reclamation activity on the overburden dumping area.

The SPOT (XS+P) data were classified using the supervised and unsupervised classification algorithms and class assignments were made through comparison to thematic and topographic maps as well as ground truth. The best result was achieved using maximum likelihood supervised classification with option: all pixels classified or 1-5% pixels unclassified. The land-cover/vegetation maps were generated using spatial smoothing filters, contrast stretching and density slicing techniques (Fig. 3).

4. RESULTS AND DISCUSSION

4.1. Landscape changes

Landscape changes are connected with the following main factors:
1) Geomechanical transformations:
Looking at the SPOT images the landscape changes are visible as an unusual disturbance of the rural (forest&crops) area, because of men-made, artificial landforms. As the result of mining operations the hug open-pit mine and the dump body were created (Fig. 1 and 2). Enormous sizes each of it, regularly shape and the spectral differences of the ground being degraded are the main recognizable features of this object (Fig. 1 and 2);
2) Electric power plant activity:
After displaying and magnifying the SPOT-Pan image one can easily recognize the electric power-plant segments: stack and vents, cooling towers, turbogenerator blocks, other buildings, high voltage lines and huge containers for slag and ashes (Fig. 1 and 2);
3) Development of transportation system:
Highway and secondary roads especially these of connected BMEC and the city of Bełchatów and also internal transportation system of BMEC one can easily observed, particularly on the SPOT-P image.

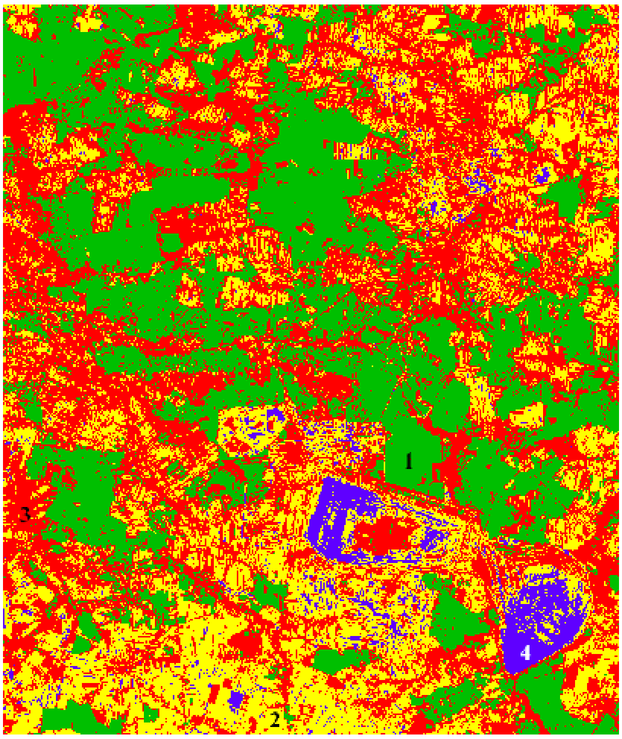

Fig. 3. Map of land-cover over the study area (1-forest; 2-crop-land; 3-grass-land&urban; 4-degra-dated areas).

4.2. Land-use/land-cover changes

Land-use/land-cover changes were assessed through comparison SPOT/LANDSAT TM data with topographic map showing the situation just before the start mining and electric power plant operations.

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The main land-use/land-cover changes are connected with:

1) forest cutting (clearing) mostly because of waste-dump, electric power plant, open-pit, and dump of overburden construction;
2) putting to death about 10 villages (one was located just above the center of open-pit-mine, another one under dump body;
3) liquidation of the two large good-organized fish-culture ponds, close to the dumping area located;
4) destruction a part of cropfields, grassland and rangelands caused by mining and industrial activity;
5) changes in regime of ground- and surface water.

Because of drainage (desiccation) system operation the surface-water bodies (pond, small lakes) and natural soil wetness area have been desiccated.

4.3. Conifer forest degradation

Conifer forest degradation features were derived by comparison the SPOT (P+XS) and LANDSAT multispectral data and the forest degradation map, which was compiled through the interpretation of the color infrared photography. It was stated, that the all forest area are degraded by BMEC influence. The most affected forest areas are surrounding the BMEC and are also located to the North and North-West direction from electric power-plant. There is also a little difference of spectral response in the SPOT/LANDSAT multispectral bands on this area. These interpretation results have been checked in the field.

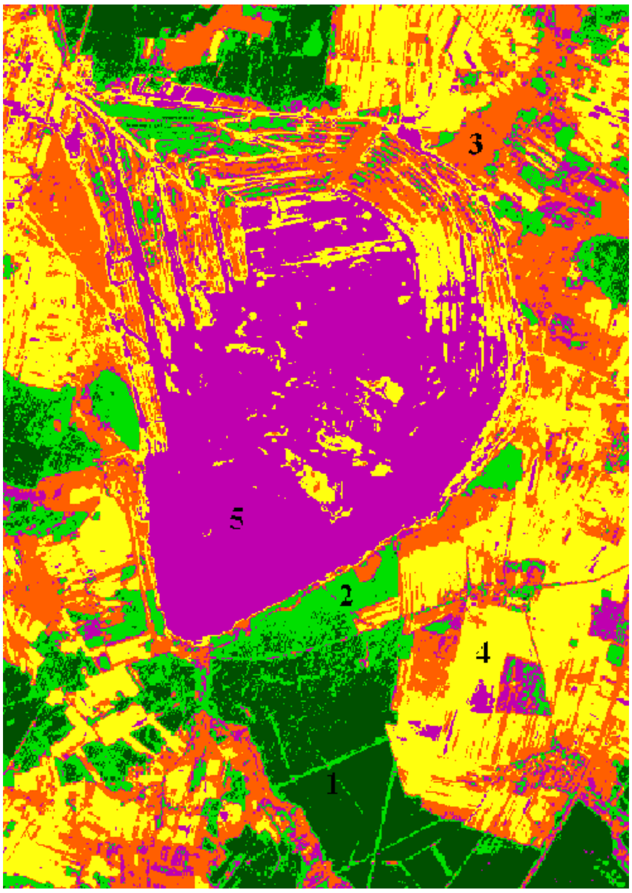

Fig. 4. Map of land-cover over the dumping area (1-conifer forest; 2-deciduous forest; 3-grass-land&urban; 4-crop-land; 5-baregrounds).

4.4. Estimation of reclamation activity

Estimation of reclamation activity on overburden dump area consists of:

1) inventory of vegetation cover with discrimination of four categories (Fig. 4 and 5):
   a) deciduous forest;
   b) brushwood and grass;
   c) brush and tress;
   d) grass;
2) quantitative approach to the assessment of the reclamation activity over the dump area. For this purpose two maps were generated:
   a) map of vegetation cover changes on N-W part of the dump area (Fig. 5);
   b) map of the reclamation stages with the five zones (Fig. 6);

- reclamation finished	4.2 %
- reclamation advanced	10.3 %
- reclamation initial	28.9 %
- reclamation experimental	18.9 %
- dumping & geomechanical operations	36.2 %
unclassified	1.5 %
Total	100.0 %

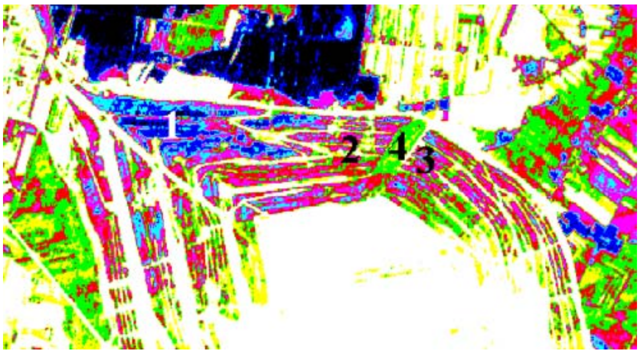

Fig. 5. Map of vegetation cover the N-part of dumping area – supervised classification of SPOT (XS+P) (1-deciduous forest; 2-brushwood&grass; 3-brush &trees; 4-grass).

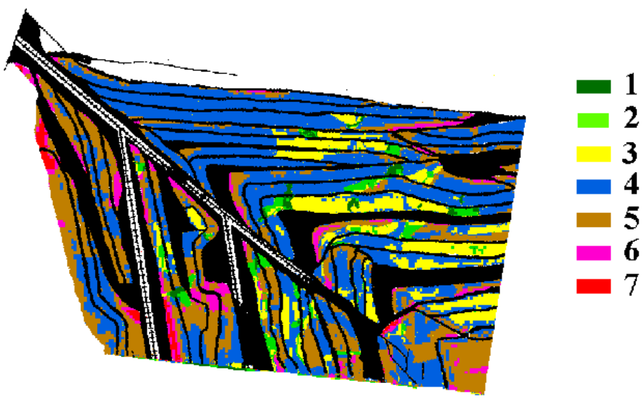

Fig. 6. Map of the vegetation cover changes of the N-W part of the dumping area (category: 1,2,3-changes in plus; 4-no changes; 5,6,7-changes in minus).

5. SUMMARY

The results of the study suggest that SPOT and LANDSAT TM images are very useful and profitable space-borne data for the environmental inventory, monitoring and mapping problems over the relative small mining-energy area. For such detailed study the main advantages of the SPOT images, comparing with other satellite systems alone, are the following:

1) owing to the high resolution of the SPOT P (panchromatic) image it was possible to recognize and to interpret even the relatively small objects and the features of the landscape, land-cover, surface texture, topography, etc.
   The SPOT-P image provides the thematic information, which is comparable with high- or even mid- altitude airborne photography (Fig. 10). This is tremendous capability of such product for thematic mapping and monitoring over the industrial areas;
2) merging SPOT-P (panchromatic) channel with SPOT-XS/LANDSAT TM (multispectral) channels and airborne photography is very useful and interesting procedure to improve the thematic interpretation. This product allows to keep very important thematic information of the multispectral sensor as well as geometric accuracy taken from the panchromatic band (Fig. 7, 8, 9);
3) SPOT-P combining with SPOT-XS and LANDSAT TM channels are providing the information which allowed to make the detailed vegetation cover inventory on the dump area and also to make quantitative approach of this vegetation cover development (Fig. 11, 12).
   For the first time it was possible to achieve a complex reclamation activity assessment in the precise and cost-effective way. This was the most significant practical attainment of the study presented;
4) SPOT-View products particularly SPOT (P+XS) should be strongly recommended for the detailed studies over the relatively small areas. The usefulness of these images to solve the monitoring and mapping problems connected with mining and electric power plant operations, is evident and has been documented in this project. The only disadvantage was that there was no possibility to get clouds free, simultaneously taken SPOT-P (panchromatic) and accurate and more impressive, that was obtained.

6. ACKNOWLEDGMENTS

The author would like to thank the SPOT IMAGE, France, for supplying the SPOT-View product as the support of this study.
The image processing analyses were mostly done by Dr. Beata Hejmanowska, which I would like to thank for her valued assistance and scientific discussion.

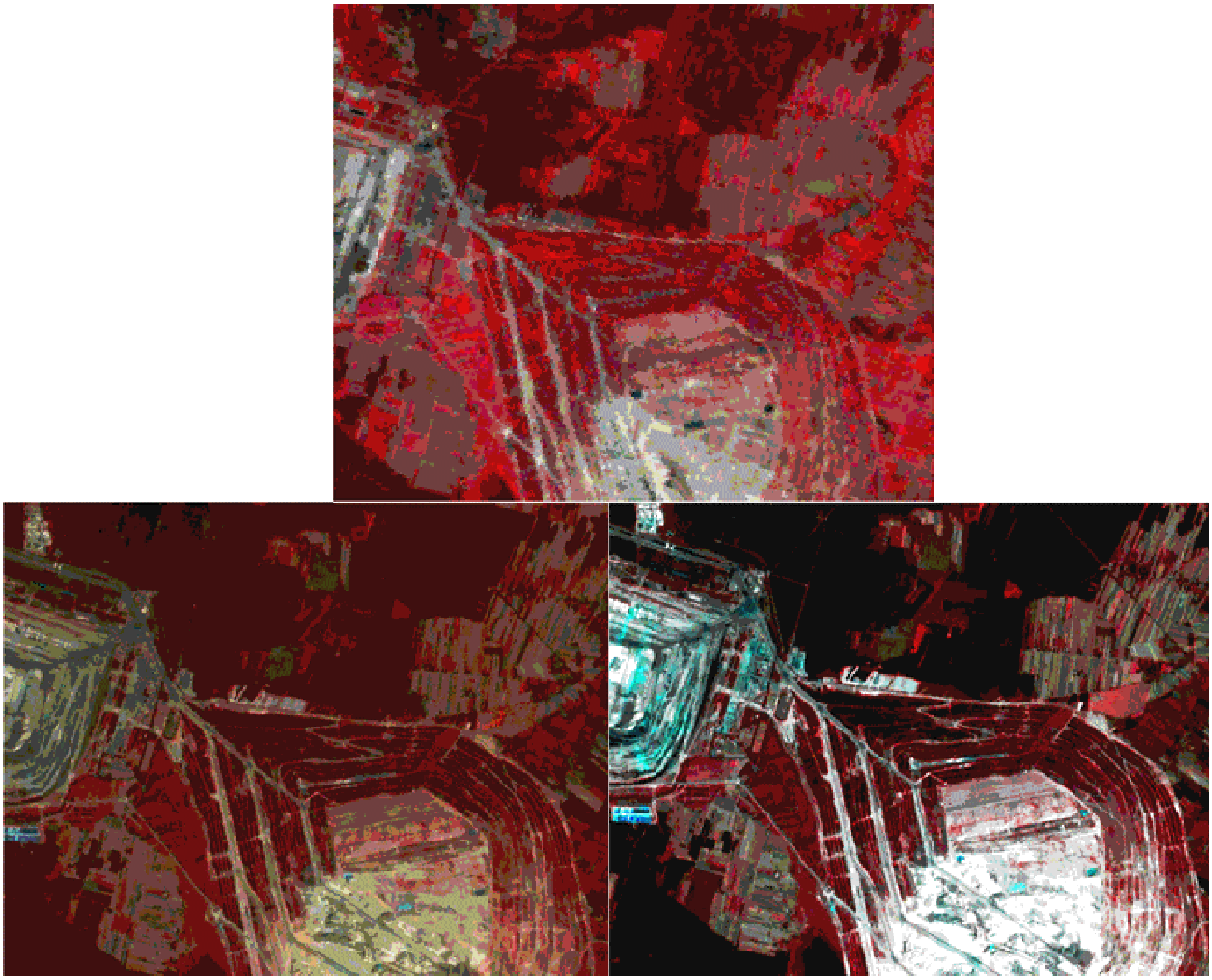

Fig. 7. Merging of LANDSAT TM (4 3 2) and SPOT PAN images (IHS transformation)

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Fig. 8. Merging of LANDSAT TM and SPOT PAN images (Jaakkola method)

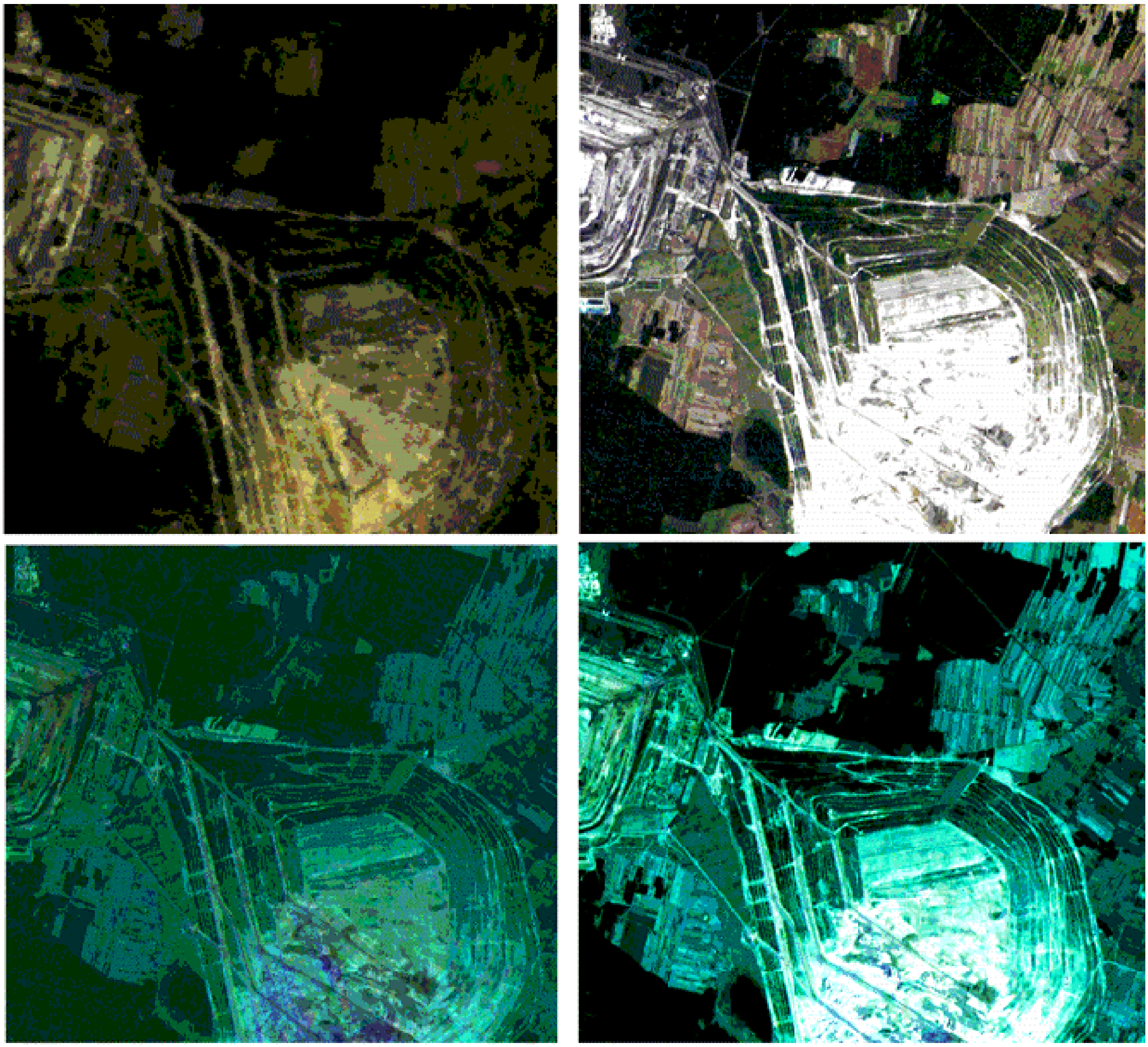

Fig. 9. Integration of LANDSAT TM and SPOT PAN images (PCA-first & second component as hue and saturation)

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Fig. 10. Comparison of the SPOT PAN image and airborne colour photography

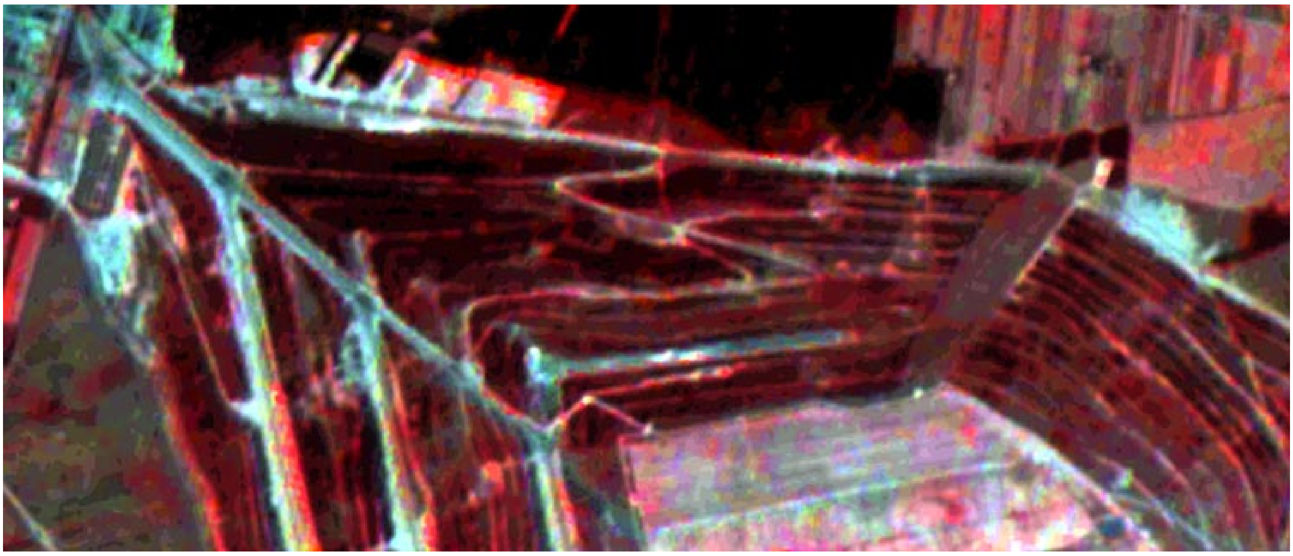

Fig. 11. Reclamation state on the dump body (LANDSAT TM and SPOT PAN IHS transformation)

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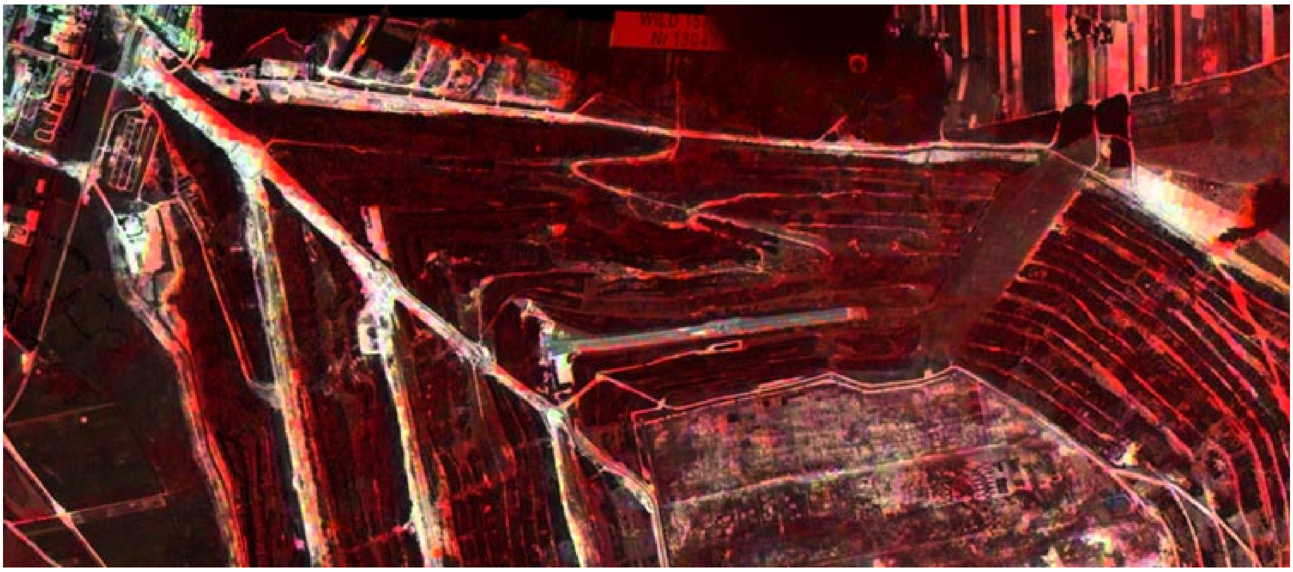

Fig. 12. IHS transformation (LANDSAT TM 4 3 2 and airborne photography)

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