THEMATIC INFORMATION CONTENT ASSESSMENT OF AERIAL AND SATELLITE DATA FUSION*

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ABSTRACT
The large Lignite Open-Cast Mine „Belchatow” located in the central part of Poland, was a study area. The main subject of this investigation was used merged satellite and aerial images for discrimination of the geological features and detection of the mining structure and geometry of the open pit mine. Visual and statistical analysis methods were used to determine the amount and distribution of information contained in the data sets. The factors that enable TM visible and infrared bands to discriminate the geological features are connected with spectral signatures of the lithological units. In particular, the carbonate, silicate, sulfate and clay mineralogies of the sedimentary rock units were responsible for the specific spectral properties. Merging the satellite and aerial images seems to be a good way for enhancement the thematic interpretability of the Landsat TM data.

1 INTRODUCTION

For many applications the benefit of obtaining highest spatial resolution is evident, particularly for land-use / land cover classification, urban studies, farming inventory and environmental monitoring problems. On the other hand, depending on the type of application and the level of landscape complexity the detection and recognition of relatively small objects is possible, if high spectral resolution images are used. Hence, there is a desire to merge both high multispectral imageries and high spatial resolution images. Using such concept one can obtain most complete and accurate resulting images an area of interest. Merging the data collected by the two different satellite systems it is possible to get a complementary information provided by each of the two sensors. Examples of such a data set are the Landsat TM which has six multispectral bands (30 m) and the SPOT PAN panchromatic mode (10 m) images. The main concept of sensor fusion is to preserve the multispectral content of images at a low spatial resolution (like Landsat TM or SPOT XS) and images at a higher spatial resolution but with a poor spectral content (like SPOT PAN). However, not all of the existing merging methods fulfil this idea. This paper discusses currently most used methods and their advantages and disadvantages connecting with the monitoring problems of an open-cast areas. For such specific and relatively small areas satellite multispectral sensors have to be merged with now available images at much higher spatial resolution.

Many of authors have been reported of successfully using pixel-by-pixel and other more complex mathematic procedures to merge Landsat spectral bands with digitized aerial photographs (Chavez, 1986; Cliche et al., 1985; Chavez et al., 1982, 1984; Ranchin and Wald, 2000). For geologic remote sensing an attempt to merge satellite multispectral Landsat MSS and TM images together with the digital aerial photographs have been also successfully done by Dennis N. Grasso (1993).

In the study presented the Landsat TM (30 m) and airborne photography (2 m) have been used for merging, with the aim of improving the spatial resolution together with a good preservation of the spectral content of integrated images. This was given the possibility of the geological features detection in the open-pit mine, reclamation activity registration on the dump body and inventory of mining operation. A quantitative comparison of all used merging methods is also carried out for the set of colour composite using approach proposed by Wald et al. (1997) and Mularz (1996).

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2 STUDY AREA

The Lignite Open-Cast Mine "Belchatow" has been chosen as a study area. It is located in the central part of Poland, southwest from Warsaw in distance 150 km approximately. The mining area consists of open-pit mine, a dump body and electric power plant (Figure 1.). A size of the open-pit mine was about 2.5 km wide by 6.0 km long and about 250 m in deep.

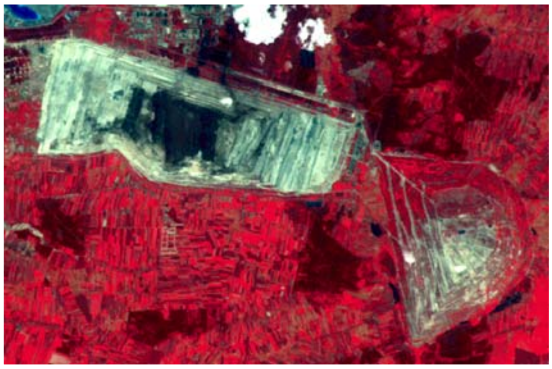

Figure 1. *The Belchatow Mining Energy Complex: a) open pit mine, b) dump body and c) power plant*

The large scale exploitation causes not only mining and many technological complications but also many of geological, engineering, planning and reclamation problems have to be solved. To monitor such a large open-pit mine fast enough and effectively using remote sensing techniques is necessary.

The lignite deposit occurs into the tectonic faultgraben formed within the Mesozoic basement. The overburden of the lignite layer consists of quaternary glacial and glaciofluvial drifts, mostly bouldor clays, sands, gravels and silts. And beneath there are the Tertiary sediments consist of variegated clays, sands, lake marls, gyttjas and limestones. The average of overburden thickness and the lignite layer is 150 m and 100 m, respectively. An opencasting is conducted on the number of the working escarpments and plains that formed the general slopes of the open-pit mine. Because the exploitation face is moving from East to West, there is a good situation for remote sensing registration, since shadowing effect is to be minimised in the forenoon hours, when airborne and spaceborne data have been registrated.

3 DATA AND METHODOLOGY

3.1 Data set

The multispectral Landsat TM image and the color aerial photographs (scale 1:26 000) were used for the merging procedures over the open-cast mine area. Landsat TM data were acquired about one month prior to the airborne photographs overflight. The diapositives of aerial photographs were than scanned with accuracy of 2 m ground resolution.

3.2 Preprocessing

A general procedure for creating data sets for the merger involved the following steps: image registration, resampling of the multispectral data sets and removing of atmospheric effect, while preserving the full spectral information. And also the digital mask was prepared to cut-off the surroundings of an open-pit mine area. The digital images from both sensors were geometrically registered to one another. Registration accuracy was evaluated at control test points, and yielded root-mean-square error (RMSE) values of equivalent ±0,8 data pixel for aerial photographs and ±0,5 data pixel for Landsat image subsets. It is indicated a good geometric integrity of the data used. After resampling procedures the remotely sensed images (satellite and airborne) characterised a large (15x) differences in spatial resolution. Thus, a kernel filter (15x15) have to be used to smooth the blocking structure of the Landsat TM data. Owning to the kernel size the original DN values of Landsat TM band ware preserved for panchromatic content from color aerial photographs, IHS (Intensity, Hue, Saturation) transformation procedure was performed and Intensity (Ie) as an equivalent of the spatial (panchromatic) information was taken for further analysis.

3.3 Merging procedures

A number of merging methods known from literature have been tested, namely: HPF (High Pass Filter), IHS (Intensity, Hue, Saturation), PCA (Principal Component Analysis), SC (Spherical

Coordinate), CN (Color Normalized), and Brovey's, Cliche et al. as well as Jaakkola's procedures. For the final assessment of the merger usefulness for monitoring of an open-cast mine area the HPF, IHS, PCA, Cliche et al. and Jaakkola's fusion formulas were chosen.

The HPF merger concept based on the high-frequency filtration of the image of the higher spatial resolution. The spatial high pass filter removes most of the spectral information from airborne (panchromatic) data. The HPF results are added (or substracted) – pixel by pixel to the lower spatial but higher spectral resolution images. This procedure indicating the merger the spatial information of the higher spectral resolution data set (Chavez et al., 1991). In the HPF procedure one can use different of the kernel size. In this study the kernel size of 31x31 pixels was used because of resolution ratio (15:1) of Landsat TM and airborn data (after Chavez, 1991).

IHS is one of the most often used methods to integrate multisensor image data (Haydn et al., 1982; Welch and Ehlers, 1987; Carper et al., 1990; Grasso, 1993). With the IHS method, subsets of three selected Landsat TM band are first transformed into the IHS domain. The panchromatic equivalent (Ie) of color aerial photographs as reference image was then substituted of the Intensity component, and the data was transformed back to the red-green-blue (RGB) color domain.

The PCA merging procedure is similar to that of the IHS method. Usually the six of the optical TM bands are used as input to the PCA procedure. In this method transformation from the spectral space of the original TM bands is performed to the new space of the principal components. As with the IHS formula histogram of the spatial (panchromatic) data is stretched to be similar to the histogram of the first principal component, extracted from TM data. The stretched image should have approximately the same variance and average as the first principal component. The results of the stretched airborne data replaced the first principal component image, before the data are transformed back into the original spectral. A spatial information is moved to all spectral bands after these data are retransformed. Because the first principal component image will have the information common to all spectral bands used, replacing the first principal component by airborne data (equivalent panchromatic band) is correct methodically. Successfully use of PCA was reported by Chavez et al., 1991; Chavez and Kwarteng, 1989. The spatial information provided by the first principal component is very stable if compare to the spectral contact of the original TM bands. The PCA merger needs further investigation because the spatial information is non-proportional retransformed to the different spectral bands (Chavez et al., 1991).

The Cliche et al. (1985) method based on the simple algebraic formulas to define relation between the multispectral and panchromatic channels. For the blue, green and red plane the following integration formula is used:

$$PTMx = sqrt(TMx \cdot PAN) \qquad (1)$$

After original Cliche et al. formula to reduce the influence of the panchromatic channel in the TM4 channel, the information in the near infrared region should be protected while including a geometric information using such formula:

$$PTM4 = 0.25PAN + 0.75TM4 \qquad (2)$$

In the study presented formula (1) was used to transform all TM bands because of the high correlation between the visible and near infrared channels, caused by the specific spectral signatures of the open-pit mine area.

The Jaakkola method assumed that the loss of geometric details on the multispectral image with regard to panchromatic image can be estimated by comparing an original panchromatic image and the new panchromatic image degraded to resolution of a multispectral image. To get the merged imagery it is necessary to multiply the TMx pixel value resampled to the PAN image resolution by the ratio of an original and degraded panchromatic pixel values.

4 DISCUSSION AND RESULTS

An important disadvantage of each of the image merging procedure is its inability to combine dissimilar spectrally and not simultaneously collected data. This is especially significant in the case of monitoring the open-cast mine area. Because of continuous mining operation the shifting in time between satellite and airborne sensor registrations should be as narrow as possible. If not, the changes caused by mining operations might be so significant, that the spatial and thematic content of satellite and aerial images became non-comparable. Landsat TM and aerial photographs used in our study have been collected within one month. Although some differences one can observed, they are not essential for merging effect.

For geologic remote sensing the fusion of visible bands and high resolution spatial data is limited to color differences of the lithological units. A significant improvement in overall interpretability of merged images is observed when the infrared bands together with visible are incorporated into the final product. That is because of unique spectral reflectance and absorption features of different geological units, in infrared region. Particularly within short-wave infrared (SWIR) region these features can be directly related to distinctive mineralogical properties (Hunt, 1977, 1979; Hunt and Asley, 1979; Grasso, 1993). Within the SWIR part of electromagnetic spectrum most geologic materials have reflectance maxima near 1.60 µm wavelength (Prost, 1980). Phylosilicate minerals such as clays have additionally reflectance minima centred at 2.20 µm wavelength. This is due to absorption effect in 2.10 to 2.35 µm region (Prost, 1980; Goetz et al., 1983) and sensitive of this absorption features was also demonstrated (Hunt and Ashley, 1979). This is the reason of widespread use of infrared part of the electromagnetic spectrum in geologic remote sensing (Rowan et al., 1974; Abrams et al., 1977, 1983; Goetz and Rowan, 1981; Lang et al., 1984, Yamaguchi, 1987; Campos-Marquetti and Rockwell, 1989; Pontual, 1989; Grasso 1993).

In general, the results of the study presented corroborated the specific spectral properties of SWIR region. A visible interpretation as well as the formal assessment using statistic approach has been indicated that the infrared bands of the Landsat system, particularly SWIR channels (TM 5 and TM 7) contained a great amount of geological information. Statistical-analysis method which was used to rank the 20 possible three band combinations based on the Optimum Index Factor (OIF) (Chavez et al., 1982). The OIF value for any of three bands subset based on the sum of their standard deviations normalised by the sum of absolute values of their correlation coefficients. In this case the largest OIF value indicates the biggest amount of information contained in a particular three band set and the least amount of duplication. Figure 2. shows that, high rankings were obtained by three-band combinations that included one or two of visible band (TM 1 and TM 3) and one or two infrared bands (TM 4 and TM 5). The next three composits contained of TM 3, 4, 5 and 7 bands had also high OIF values, while the relatively smaller OIF values characterised four composites that included TM 1, 2, 3, 4 and 5 bands. Explicitly low rankings were obtained for the TM 1, 2, 3 and 4 band combinations, while the middle rankings were observed for the TM 1, 2, 3, 4 and 7 bands combinations.

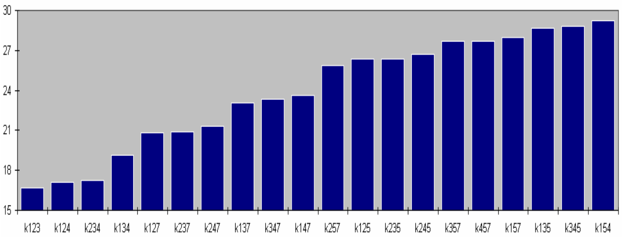

Figure 2. *The OIF (Optimum Factor Index) values for three-band original Landsat TM bands combinations*

The same procedure was performed to determine the amount and distribution of information contained in the three-pair subsets after merged of Landsat TM and aerial photographs. In order to determine the OIF values the different fusion methods were assessed taking into account a total variance of each data subset. For the six subset of Landsat TM bands combinations (TM 123, 134, 234, 145, 247, 457) the rankings of using merging procedures in shown on Figure 3. One can easily observed that the HPF (High Pass Filter) method characterized the maximum of OIF values for the full data set being analyzed. The merger of remotely sensed images based on PCA (Principal Component Analysis) concept high rankings were obtained full set of Landsat bands combinations. For the IHS (Intensity, Hue, Saturation) merging method relatively low rankings were observed. Another words, the HPF transformation seems to be the best merging method being tested, than PCA and IHS formulas, when taking into account the average of the amount of the additional information generated by the merger. Looking at the particular three bands combinations one can easily observed interesting regularity, that for the Landsat TM (145 and 457) bands the high rankings were obtained, independently of the merging method have been used. Also the Landsat TM (247) spectral bands might be effectively combined with the spatial information of aerial photographs.

The relatively less promissive from interpretations point of view and the total amount of information are combinations which contained in the three-pair subset the four Landsat TM bands (123, 134, 234). This was probably because, low rankings usually resulted from contiguous band combinations caused by more highly correlation between these bands, if compared the others. Also the similar conclusions are indicated by Chavez et al. (1984). Table 1 shows the correlation coefficients of that Landsat TM bands versus the intensity (after RGB transformation from color aerial photographs). It is clearly visible the Landsat TM 1, 2, 3 and 4 bands provide almost the same information (high correlated), while TM 5 and 7 bands are in fact different from other (relatively low correlated). Thus, the three band combinations, which contained one or two of these channels have been characterized by the largest OIF values, before and after merging.

Statistically, taking into account the Optimum Index Factor (OIF), Determinant Analysis Method (DET) and the Relative Average Spectral Error (RASE), the high ranks for Landsat TM (541) and TM (754) bands combination were obtained. It should be stressed, that for TM (754) color composite the RASE factor has minimum values independently of the merging method being used (Fig. 3). Also for TM (742) Landsat bands combination the relatively high rank was observed. After fusion, the Landsat TM (432) and TM (321) color composites are clearly less promissive, from the statistical analysis point of view, when comparing to other band combinations.

The results we obtained are very similar to the ones reported by Rigol J.P. and Chica-Olmo (1998). They indicated TM (541), TM (742) and TM (475) triplets being highly useful in lithological discrimination studies. The merged images have the great advantage with respect to the original Landsat multispectral images, of

Table 1. *Correlation coefficients of Landsat TM bands and equivalent of panchromatic image (Ie)*

	TM 1	TM 2	TM 3	TM 4	TM 5	TM 7	Ie
TM 1		O,982	0,975	0,935	0,587	0,686	0,699
TM 2	0,982		0,992	0,966	0,583	0,691	0,712
TM 3	0,975	0,992		0,975	0,622	0,726	0,717
TM 4	0,935	0,966	0,975		0,628	0,720	0,702
TM 5	0,587	0,583	0,622	0,628		0,938	0,430
TM 7	0,686	0,691	0,726	0,720	0,938		0,542

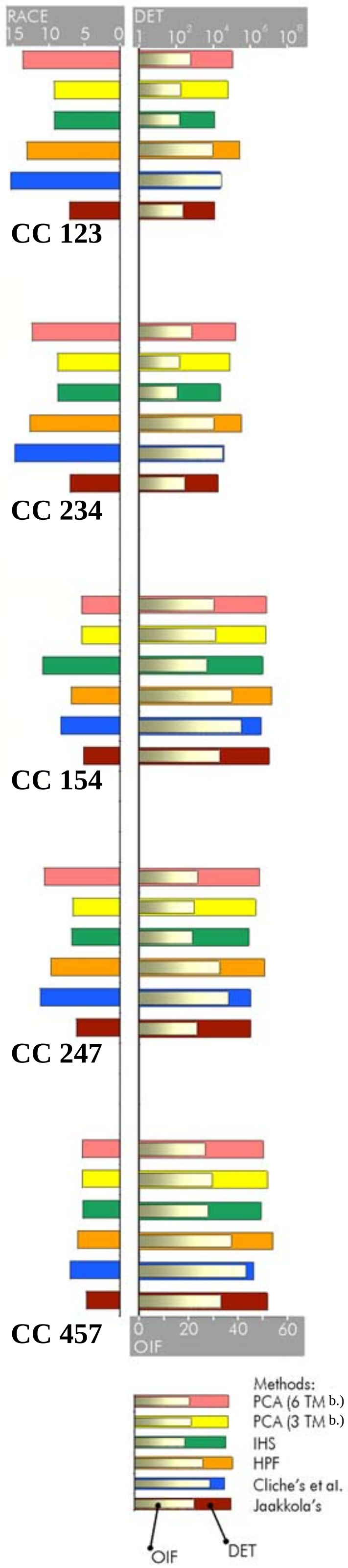

Figure 3.
Diagram ilustrating the statistical evaluation of different merging methods for different Landsat TM three bands combinations.

providing more abundant and accurate geological and structural information, which is important for visual thematic interpretation within the field of geological mapping.

Table 2. shows the correlation coefficients of the TM bands before and after merging procedures, as well as panchromatic equivalent image (Ie). Among the three tested merging methods the HIS distorted the spectral characteristic of the Landsat data the most. The reason is because the intensity image that is replaced by the airborne (the equivalent of panchromatic image – Ie) can be different depending on the TM bands combination used. In all tested three band combinations (TM 123, 134, 234, 247, 145, 457) very high correlations with panchromatic equivalent image (Ie) are observed (Table 2.). The PCA method also distorted the spectral characteristic of satellite TM data, but the distortions were less then those in the IHS method.

Table 2. *Correlation coefficients of TM bands after merging for different methods being tested*

TM X	HPF	IHS						PCA
nTM 1	0,580	0,703	0,720			0,856		0,716
nTM 2	0,493	0,738		0,749	0,845			0,573
nTM 3	0,622	0,720	0,735	0,722				0,721
nTM 4	0,602		0,717	0,703	0,823	0,868	0,857	0,829
nTM 5	0,688					0,421	0,429	0,848
nTM 7	0,567				0,535		0,598	0,737
Ie								
nTM 1	0,778	0,993	0,978			0,926		0,953
nTM 2	0,751	0,994		0,985	0,938			0,935
nTM 3	0,794	0,996	0,994	0,993				0,970
nTM 4	0,784		0,977	0,983	0,948	0,930	0,914	0,948
nTM 5	0,616					0,907	0,980	0,765
nTM 7	0,672				0,891		0,979	0,897

The correlation of HPF merged image with panchromatic (Ie) image were less than those in PCA method. It should be stressed that in SWIR bands (TM 5 and 7) after merging the spectral information contents were preserved better than in the visible (TM 123) and near infrared (TM 4) bands. In PCA and HPF method correlation coefficients were low contrary to expectation.

When taking into account all tested merging procedures, the Jaakkola's and Cliche et al. methods became the best to preserve the multispectral content of the original Landsat TM bands. On the other hand the IHS and PCA methods distort more or less the spectral characteristic of the satellite TM data depending on the particular band combinations (Table 3.). The HPF method distorted the spectral content of the Landsat TM data the most, especially for band TM2 (green), TM7 (SWIR) and TM1 (blue).

Table 4 contains the ranking based on visual interpretation of different merging products, to rate them on a scale from 1 to 6+ (1 – poor quality, 6 – good quality, 6+ - very good quality). Notice the great distribution of the scores in different fusion methods for particular band combinations. This is because the best merging method for visual interpretation is dependent on the geological phenomena and mining infrastructure that one is looking for. From the interpretation point of view the IHS and PCA merging methods were the best for TM (754), TM (432) and TM (742) Landsat bands combination.
An important result of the merger is that the different three-band combination

Table 3. *Correlation between the original Landsat (TMx) and the merged (nTMx) bands.*

		Band (nTMx)						
Method	**Band (TMx)**	**1**	**2**	**3**	**4**	**5**	**7**	**Ave-rage**
PCA - 6 b.	**all**	0.716	0.573	0.721	0.829	0.848	0.737	0.737
PCA - 3 b.	**123**	0.753	0.587	0.780				0.707
	134	0.687		0.711	0.781			0.726
	234		0.749	0.723	0.814			0.762
	154	0.657			0.740	0.813		0.737
	247		0.584		0.817		0.817	0.739
	457				0.822	0.582	0.470	0.625
IHS	**123**	0.703	0.738	0.720				0.720
	134	0.720		0.735	0.717			0.724
	234		0.749	0.722	0.703			0.725
	154		0.845		0.823		0.535	0.734
	247	0.856			0.868	0.421		0.715
	457				0.875	0.429	0.598	0.634
HPF	**all**	0.580	0.493	0.622	0.602	0.688	0.567	0.592
Cliche	**all**	0.865	0.877	0.876	0.866	0.599	0.712	0.799
Jaakkola	**all**	0.909	0.918	0.912	0.904	0.700	0.758	0.850

furnished valuable lithologic information for detection and recognition of the geological units within the overburden as well as lignite deposit in the open-pit mine. Furthermore, geologic analysis was simplified by both color and spatial information. It is evident also, that the mining infrastructure namely machines, transformation facility, buildings etc., are clearly visible and recognisable on the fusion products.

Table 4. *Results of visual interpretation.*

Method	**Composit**					
	CC 321	**CC 431**	**CC 432**	**CC 451**	**CC 742**	**CC 754**
PCA – 6 bands	4	6+	6+	5	6	5
PCA – 3 bands	4	5	5	5	6	5
IHS	6	6	5	6	5	6+
HPF	2	5	4	5	5	5
Cliche's et al.	4	4	3	4	5	4
Jaakkola's	5	5	4	5	4	6
Brovey's – 6 bands	2	3	3	2	3	2
Brovey's – 3 bands	1	4	4	2	2	3

5 CONCLUSIONS

The merger is a useful and powerful tool for combining spaceborne and airborne images. Using the different merging techniques the Landsat TM data could be enhanced by aerial color photographs spatial content. It was stated, that the merged images could be a very useful tool for monitoring open-cast mine areas. After merging transformation a significant improvement in overall interpretability of the multispectral Landsat TM data was observed, particularly for the geological features detection and delineation. The merger images more clearly showed the boundaries of the lithological units within the deposit overburden and the lignite layer due to textural and color differences. Also the mining infrastructure elements and geometry of the open-pit mine and the dump body could be explicitly recognized and identified on the merged images. Based on visual interpretation and statistical analysis method using OIF (the Optimal Index Factor), Determinant analysis method (DET) and Relative Average Spectral Error (RASE) the best results were obtained for HPF (High Pass Filter) and PCA (Principal Component Analysis) fusion methods. Surprisingly, the IHS (Intensity, Hue, Saturation) merging procedure is less efficient for the open-cast mine monitoring purposes then others tested methods. High rankings were observed for three-band combinations that included TM 451 and TM 754 Landsat data. This is because of the specific spectral properties of infrared region of the electromagnetic spectrum, particularly for the lithologic features detection. The relatively low correlation between the short-wave infrared bands (TM5 and 7) and the visible bands (TM1, 2 and 3) or even infrared band (TM4) also indicated that SWIR bands provided different thematic information then others spectral bands.

The Jaakkola's and Cliche et al. methods became the best to preserve the multispectral content of the original Landsat TM bands. The HPF, IHS and PCA fusion methods distort more or less the spectral characteristic of the satellite TM data depending on the particular band combinations. The ranks of merging methods based on the visual comparison of the IHS and PCA methods were the best fot TM (754), TM (432) and TM (742) bands combinations.

The results of this investigation indicate that the spatial resolution limitations in the Landsat TM data might be effectively reduced by the merger with high-resolution aerial photographs. Thus, the monitoring of the open-cast mine environment can be done more accurate and efficient, with regard to the delineation of lithological units as well as mining structure inventory and the geometrical elements of open-pit mine and dump body identification. The resulting false color composites of spatial resolution similar to those of the reference aerial images can be successfully used for monitoring of open-cast mine area. Such products will prove useful to investigators seeking to maximise the amount of information extracted from satellite multispectral imageries.

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