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APPLICATION OF REMOTE SENSING IN THE RED MUD ENVIRONMENTAL DISASTER IN HUNGARY

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Abstract: Data collection with the help of remote sensing is significant in the field of information about the environment quickly and effectively. In case of the red mud disaster in Ajka, Hungary Oct. 4, 2010 our group of researchers carried out an extensive remote sensing data collection with the co-ordination of Science Council of the Committee of the Government Coordination Commission, applying the most up-to-date technologies of remote sensing and data processing. In this publication besides the main points in planning and executing air shots we also summarize the results of data processing with image analysis during the evaluation of the catastrophe and the compensation period.

Keywords: Red Mud, Environmental Protection, Remote Sensing, Image Processing, Hyperspectral Imaging, Diagnostic, Thermography, GIS

1. INTRODUCTION

Hungary's largest ecological disaster took place on October 4, 2010 at 1:30 p.m. when the western dam of cassette X of the mud reservoir, belonging to a privately owned company, Magyar Alumínium Zrt (Hungarian Aluminum Co.), had ruptured. Due to the ruptured dam, a mixture of ca. 1700 thousand m^3 (our calculated value) of red mud and liquid inundated the lower sections of the settlements of Kolontár, Devecser and Somlóvásárhely via the Torna creek. The spilling red mud flooded 800 hectares of surrounding areas. The most extreme devastation was caused in the villages of Devecser and Kolontár, which are located near the reservoir (Official Website of the Hungarian Government "Redsludge" tragedy).

Besides remote sensing with the help of visible (VIS) devices, studies applying Near Infrared (NIR), Far Infrared (FIR) cameras, and hyperspectral (HYS) devices are getting more and more common (Kozma-Bognár & Berke, 2009; Kováts, 1998; Kováts, 2002). Applying FIR cameras (with a band of 8µm-14µm) has become a general routine in the remote measurement of temperature in case of objects, based on thermal radiation (Anda, 1994; Kováts, 1998; Kozma-Bognár, et al., 2012). There are frequent inspections for identification of faulty spots with the help of devices of different manufacturers, mainly in the fields of electric network, machines and health care. The use of FIR cameras for martial and provost purposes is also remarkable. In Hungary there are investigations based on not only VIS, NIR and FIR recordings but in the common fields. For aeronautic and on-the-spot measurements we have developed, tested and applied devices with high resolution and an ability to record multi-spectral/hyper-spectral image data (Frank et al., 2010). We have worked out unique diagnostic and data processing methods to make the optimal integration of images deriving from different methods and sensors possible. This complex knowledge allows us to evaluate and reconstruct events having happened genuinely and also plays a great role in prevention. With the help of control studies disasters could be avoided.

The major difficulty of the task derived from the fact that there has not been such a mud catastrophe in the history of mankind, which could make the planning and execution of remote sensing assessment, based on existing scientific and other works. Revising recent catastrophes, the results of a similar case and a study on technologies applied in case of oil disasters were indirectly used during the planning stage of work. The first ecological disaster was the Aznalcóllar mine tailings spill. It was one of the largest environmental pollution accidents in Spanish history. Although this disaster have been dealt with by a number of scientific studies (Grimalt & Macpherson, 1999; Grimalt, et al., 1999; Kemper, 2003) the Spanish catastrophe happened in the territory of a national park, isolated from inhabited areas, whereas the Hungarian catastrophe occurred in an inhabited and cultivated area. This way we had to face unique problems during our evaluations aiding the post-damage rescue work (Dávid, 2010; Dávid, et al., 2011; Szabó, et al., 2010). The phase of planning was aided by studies dealing with sensors used in aeronautic assessment, in case of oil catastrophes (Nand et al., 2008; Salem, & Kafatos, 2001; Salisbury, et al., 1993) and by works dealing with spectral data processing methods (Chein, 2003; Chein, 2007; Grahn, & Geladi, 2007; Mandelbrot, 1983; Schowengerdt, 2007; Varshney, & Arora, 2004).

However, our major help was the 2-decade professional (planning, flying and data processing) experience of the participating team.

2. PURPOSE OF DATA COLLECTION

During the planning of remote sensing data we aimed to gain short-, mid- and long term results. The main (short-term) purpose of remote sensing recording was to monitor the investigation of environmental damage, to locate the area of contamination precisely, to estimate the concentration of substances in the mud and to estimate the status of the flooded area.

We also aimed to provide geodetic data acquired with the help of remote sensing, necessary for high-resolution visual information gained from specific spectral ranges and for the realistic post-modelling of the event (mid-term). Our further goal was to provide information helping to reveal the causes leading to the tear of the dam wall and to make proposals on further studies to be carried out.

During the recording of images we put an emphasis on recording accurate and precise data, also applicable to long-term studies and inspection. Recordings were carried out in the course of 2 days, with the help of 3 planes. (Table1).

3. DATA RECORDING

The peculiarity of this event needed unique planning and implementation. Data collection with the help of remote sensing – according to the complex aims - was carried out by a number of experts participating the project. Besides, we paid special attention to on-the-spot data collection at the time of air-shots, to the opportunity of processing the different remote-sensing technologies and to the collection of data corresponding both short and long term processing goals. Table 1 and figure 1 shows basic data about the images gathered during our flights and air-shots.

4. DATA PROCESSING

Before the assessment of images the necessary pre-processing tasks had been carried out: synchronization in time and place, filtration of optical and sensor-made noise, radiometric and geometric correction.

Table 1. Main parameters of data collection with the help of air-shot

	Visible data (VIS)	Near Infrared data (NIR)	Far Infrared data (FIR)	Hyper-spectral data	LiDAR data
Type of sensor	Canon CMOS	Canon CMOS IR	Hexium Infra Diagnostic System 110	AISA Eagle	Leica ALS 60
Time of flight	2010.10.11. 14:00 - 18:00	2010.10.11. 14:00 - 18:00	2010.10.11. 14:00 - 18:00	2010.10.10. 11:00 - 14:30	2010.10.11. 12:00 - 14:00
Height of flight	350 m, 1000 m	350 m, 1000 m	350 m, 1000 m	1650 m	800 m
Spectral band	400-700 nm	720-1150 nm	8000-14000 nm	400-970 nm (253 bands)	-
Geometrical resolution	0,2 m	0,2 m	0,6 m	1,1 m	4 Pts/m^2
Data recording	14/16 bit/pixel	14/16 bit/pixel	14/16 bit/pixel	14/16 bit/pixel	16 bit

During the processing of data we partly used our innovative programs - Spectral Fractal Dimension (SFD) - based processing (Berke, 2007; Authors Internet site of SFD) processing of FIR images (Kováts, 1998), and also special GIS and image processing software (ITT ENVI, Specim CaliGeo, Erdas Imagine, ESRI ArcGIS).

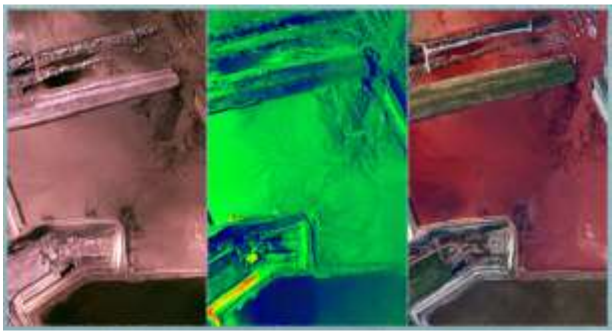

Figure 1. Main type of images of data collection with the help of air-shot - Near Infrared (NIR, left), Far Infrared (FIR, middle) and Visible (VIS, right)

5. RESULTS

The evaluation of data provided by different remote sensing technologies was carried out in parallel, in consideration of the seriousness of the situation, applying unique and integrated data processing methods. With the help of our own method based on the fractal system we identified the noisy bands, the optimal image bands from among the hyperspectral, VIS, NIR and FIR images (Kozma-Bognár & Berke, 2009; Kozma-Bognár & Berke, 2010) and also the muddy areas based on Spectral Fractal Dimension curves (Berke, 2007; Berke, 2010; Kozma-Bognár & Berke, 2009), (Fig. 2).

In order to compute Spectral Fractal Dimension (more than two image layers or bands and equal to spectral resolution), the definition of spectral fractal dimension can be applied to the measured data like a function (number of valuable spectral boxes in proportion to the whole number of boxes), computing with simple mathematical average as follows (Berke, 2007; Berke, 2010):

$$SFD_{measured} = \frac{n \times \sum_{j=1}^{S-1} \frac{\log(BM_j)}{\log(BT_j)}}{S-1} \qquad (1)$$

Where

- n – number of image layers or bands
- S - spectral resolution of the layer, in bits
- BM_j - number of spectral boxes containing valuable pixels in case of j-bits
- BT_j - total number of possible spectral boxes in case of j-bits

The number of possible spectral boxes (BT_j) in case of j-bits as follows:

$$BT_j = (2^S)^n \qquad (2)$$

Figure 3. Localization of cracks, breaks and slivering in high resolution visible image

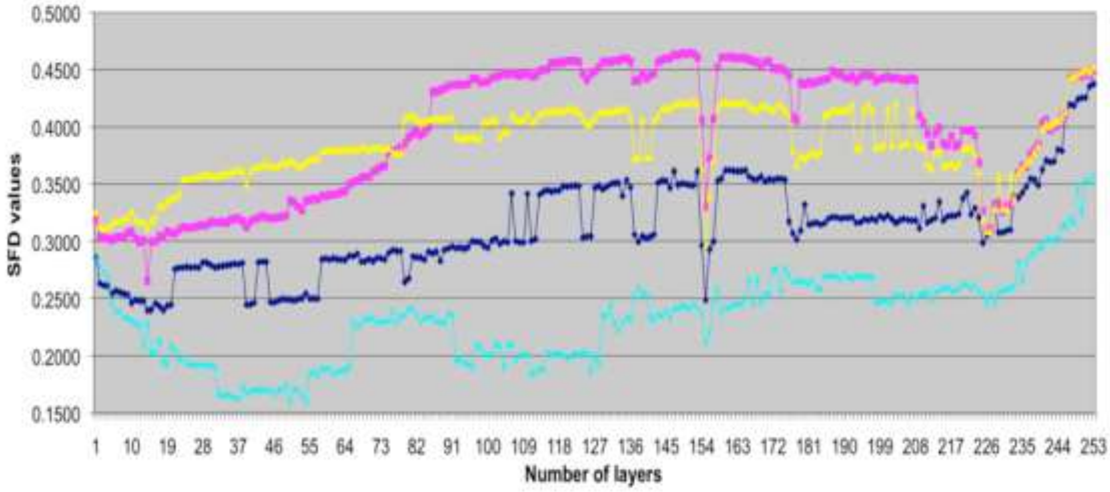

Figure 2. 'Spectral fractal fingerprints' of mud samples in cassette X. Spectral Fractal Dimension values based on AISA Eagle hyperspectral image data - dark blue (clear inner mud), pink (inner mud near the dam), yellow (mud flooding the western side), blue (alkaline in the plant)

Based on the air-shots we have defined the movements involving the Northern wall of the dam together with their causes and we have localized the cut-off points and the slivering of the wall (Fig. 3).

We have quickly identified the wet, leaking areas and mechanism of the cracks in the images shot near the reservoir. During the lateral examination of the dam wall we studied clues alluding to cracks and leaks (Fig. 3, Fig. 4 and Fig. 5).

Examination of the joint wall of reservoirs IX and X was a key issue in terms post-damage rescue work and the security of surface examination. Based on the NIR and FIR air shots and photos about the side of the dam wall we could state that there was no sign of leakage or tear. The status of the two reservoirs was stable seven days after the tear so further surface studies on the wall could be taken.

Considering the reference surfaces we have managed to define the elevation of mud in the reservoir before the tear of the wall and also the amount of mud flooding out of the reservoir.

The reference level of the mud in the reservoir before the tear was defined with the help of data gained with stereo evaluation of air-shots in September 2010.

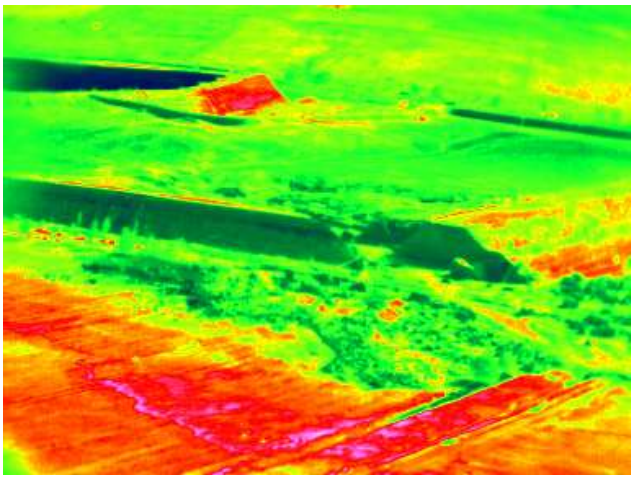

Figure 4. Identification of wet and dry areas near the reservoir in lateral's thermo-shot (warner condition because of dryer surface - red in bottom, cooler condition because of flowing off - dark green in bottom).

The area after the tear of the barrier wall was given by a measurement with LIDAR technology (Fig. 6). The volume between the two areas was defined by their intersection. The 'reconstruction' of the broken piece of wall was also made based on the shots above. We have also defined the cross-section and longitudinal section of the reservoir.

After the geometric and radiometric correction of hyperspectral images we classified the area. We applied the SAM (Spectral Angle Mapper) method for the impoundment of the flooded area based on spectra on-the-spot.

Figure 5. Signs of wetness near the northern dam section in NIR air-shot /with the arrow showing the direction of slope/

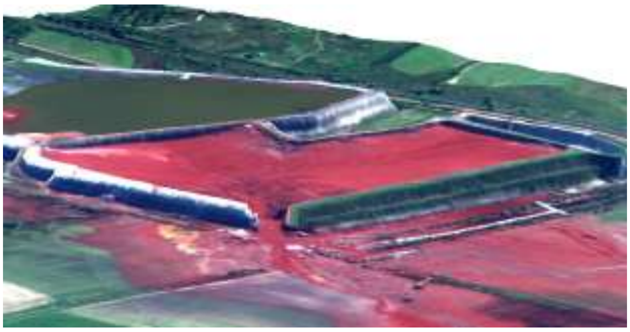

Figure 6. The LIDAR image used for the definition of the amount of mud having flooded out of the reservoir

We applied different classes (end members) according to the surface cover. The wet phase, with dry matter content less than 30%, was defined separately. When applying the SAM, the angle value was optimized based on the control areas. After the area impoundment we defined the spectra correlating with the thickness of mud (in case of a mud with 30-70 percent by mass) with the help of regression analysis, based on on-the-spot samples.

Based on the RMLI (Red Mud Layer Index) calculation (Chi, et al., 2008) from the 550 nm and the 682 nm band cassette

$$RMLI = \frac{B682nm - B549nm}{B682nm + B549nm} \quad (3)$$

we defined the threshold values for 4 thickness categories of previously marked areas (Fig. 7 and Fig. 8).

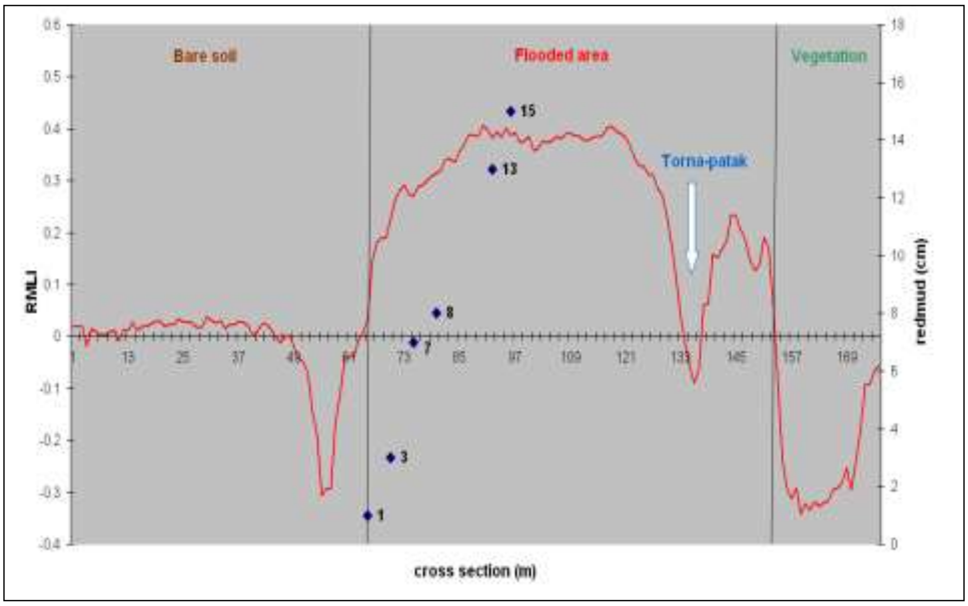

Figure 7. Hyperspectral mosaic (RGB) and areas covered by layers of different thickness (pink - 0.01-0.5 cm, orange - 0.5-3.0 cm, yellow - 3.0-9.0 cm, red - more than 9.0 cm and blue - liquid red mud)

Figure 8. Field samples (red mud thickness) and RMLI data on the examined cross-section of flooded area (blue dots: red mud thickness (cm) of field samples, red line: RMLI).

Based on data from the assessment further analysis and modelling processes have been carried out: a simulation of the tear of the dam wall, suffusion intensity calculation and spread modelling. Based on our analysis, operational steps have been taken by the authorities: planning and building of embankment, planning of prevention and preparation of compensation. Scientific duties have been assigned in case of a catastrophe and methodological protocols have been defined.

6. CONCLUSIONS

After the evaluation of data from VIS, NIR and FIR air shots and the discussion with decision-makers the disaster relief commissioner stated that all damage windup and reconstruction work would be exclusively done or confirmed by the researchers of Hungarian Academy of Sciences (including our group of researchers). Our group of researchers carried out an extensive remote sensing data collection with the controlled by the Science Council of the Committee of the Government Coordination Commission, applying the most up-to-date technologies of remote sensing and data processing.

Fast and global air photography of the reservoir and its surroundings and the fast evaluation of data made it possible to carry out a precise and reliable status control. The results gained could be used during the damage windup. As a result of this examination suggestions were made for further surface inspection.

Digital data recorded during the examination provide a good basis for future evaluation and are precise and adequate enough for future studies.
We have a practical background and technical practice to make condition monitoring of industrial storage establishments and different dams.

This disaster revealed that in most countries there is not a plan for the aligned research in case of such catastrophe. Research methods for each workgroups have also been worked-out. The results mentioned above could be gained due to the aligned and collected work of research groups.

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