JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 12, No. 1, January 2010, p. 159 - 164

Optospectral techniques for mining waste characterization in Baia Mare region, Romania

M. ZORAN*, R. SAVASTRU, D. SAVASTRU, M. N. M. TAUTAN, S. I. MICLOS, D. C. DUMITRAS[a], T. JULEA[a]
National Institute of R&D for Optoelectronics, Remote Sensing Dept., MG5 Bucharest -Magurele, 077125 Romania
[a]*National Institute for Laser, Plasma and Radiation Physics -Laser Department, MG-36, RO-077125, Bucharest*

Mining waste impacts on the environment are related to the biophysical and spectral footprints changes in the waste disposal areas and resulting loss of land productivity, direct and indirect effects on different agroforest, urban and aquatic ecosystems. The aim of this paper was to evaluate and characterize selected hazardous waste disposal sites in Baia Mare region, Romania. Use of Landsat TM, ETM and IKONOS satellite data over 1989- 2007 period stressed land cover changes in some mining industry test areas. Accuracy of image processing results (mineralogical classification) was confirmed through ground sampling and analysis of reflectance spectra with portable GER 2600 spectroradiometer.

(Received December 15, 2009; accepted January 20, 2010)

Keywords: Satellite remote sensing, Mining waste, Environmental impacts

1. Introduction

Metal mining waste from extractive and processing of mineral resources represents one of the largest industrial waste streams with serious environmental consequences in Romania. It involves materials that must be removed to gain access to the mineral resource, such as topsoil, overburden and waste rock, as well as tailings remaining after minerals have been largely extracted from the ore. From chemical activity point of view, some of these mining wastes which are inert do not represent a significant pollutant threat to the environment but other fractions, in particular those generated by the non-ferrous metal mining industry, may contain large quantities of hazardous substances, such as heavy metals. Through the process of extraction and subsequent mineral processing, metals and metal compounds have the tendency to become chemically more active, resulting in the generation of acid or alkaline drainage. So, the monitoring and surveillance of mining tailings areas is a very important management activity involving residual processing chemicals and elevated levels of metals. Usually, mining tailings are stored on heaps or in large ponds, being retained by means of dams. Through collapse, the dams may have severe impacts on environment and human health and security. Can be mentioned a lot of accidents like in 1979 Church Rock spill in New Mexico [1], the 1996 Porco dam failure in Bolvia [2], the 1998 Aznalcóllar dam failure in Spain [3] and in 2000 Aurul tailings dam failure in Maramures County, Romania [4].

Metal mining industry has a wide-ranging significant impacts on the environment. From the extraction of metal aggregated ore bodies to the crushing and refining of the mineral, large quantities of pollutants are generated both directly and indirectly. These related mining wastes pose serious threats to ecosystems and to human quality of life, having a negative impact on the natural resources, particularly soils, vegetation, air and water. In order to minimize or avoid the potentially serious environmental problems in this industry must be taken a series of preventative measures and state-of-the art environmental management practices. It requires implementing a number of highly efficient pollution prevention and waste minimization technologies and strategies that collectively reduce the quantities of pollutants released from metal mines into the natural environment.

Serious impacts like land degradation through erosion and dust deposition may have environmental and socio-economic consequences and be extremely difficult and costly to be addressed through remedial procedures. In order to ensure the long-term stability of mining waste disposal facilities and to prevent or minimize any water and soil pollution arising from acid or alkaline drainage and leaching of heavy metals is very important as extractive industries wastes to be properly assessed, surveyed and managed through modern geospatial and in situ monitoring systems. The scientific and safe management of waste from extractive industries in Romania must be done at EU level in accordance to Directive 2006/21/EC and the available reference techniques approved by EU legislation [5].

2. Use of satellite remote sensing imagery

As an integrated part of the advanced Information Technology and Telecommunication Infrastructure, satellite remote sensing imagery provided by multispectral and multitemporal time series satellite data is a very useful investigation tool of mining waste cover screening, mapping and monitoring at local and regional scales of areas containing multiple sources of mining-related heavy metals. Is based on building spectral databases, global large datasets, refining validation, calibration procedures in multi-source, multi-temporal environment. Atmospheric influences on satellite data also increase the difficulty of comparing broadband remote sensing data with laboratory or field spectra. Major improvements are especially in the hyperspectral opportunities, data fusion experiences, storage, management and retrieval of large datasets. The accelerating impact of the available enabling technologies is very important in Earth's features extraction, interpretation by digital image processing, pattern recognition and features identification. During the last decades, with the advent of new, very high spatial resolution optical sensors (*e.g.* the current Indian IRS-1C and US Space Imaging IKONOS, QuickBird and OrbView systems) and Interferometric Synthetic Aperture Radar (InSAR), the practical value of remotely-sensed data has increased significantly. However, these new sensors demand new information-extraction methods.

Mining waste impacts on the environment are related to the biophysical and spectral footprints changes in the waste disposal areas and resulting loss of land productivity, direct and indirect effects on different agroforest, urban and aquatic ecosystems.

The environmental impact of a tailings dam failure cannot be fully established without a digital mapping of affected area as well as a complex characterization of the potential toxicity and mobility of the contaminant metals involved in the ecosystems.

Mining for mineral resources can seriously alter the composition of the natural landscape, disrupting land use and drainage patterns, contaminating soil and water resources, and affecting habitats for wildlife.

Several mine accidents have brought back to the attention of the media, public and decision-makers the problem of potential emissions from metal mining sites, highlighting the priority of prevention as opposed to aftercare. The understanding of the full range of pressures due to emission sources as the result of exploitation of mineral resources and abandoned mines can be achieved through compilation of the inventories, the assessment of the environment quality threatened by emissions originating from mining, as well as the evaluation of impacts on the environment through the degradation of the ecosystems, quality of life, including human health, cultural resources, recreational value. The screening and ranking of all the pressures should be scientifically linked to the impact assessment and prevention of air, water, and soil and vegetation pollution from mines and quarries. Scientific achievement must be done through combining existing GIS inventory data with remote sensing applications and site assessment based on geo-environmental information.

3. Optospectral techniques for mining waste characterization

Optospectral techniques are becoming increasingly important science for advancing understanding of environmental processes, conditions, and spatio temporal changes. Significant advancements in sensor technology and processing algorithms have resulted in technical capabilities that can record and identify earth surface materials based on the interaction of electromagnetic energy with the molecular structure of the material being sensed.

Spectral patterns of different mineral mining waste can identify certain compounds, materials, and conditions based on the interaction of photons with the molecular structure of the target material.

Satellite remote sensing can help to rapidly assess the dimension of mining waste risk and therefore better manage such a geohazard. Satellite remote sensing and hazardous terrain mapping can play key roles in the management and mitigation of natural disasters [3]. Digital map data products can provide information on various aspects of the mining waste areas. Accurate quantification of the extent of mining activities in Baia Mare region, Romania is important for assessing how this LCLUC (Land Cover Land Use Changes) affects ecosystem services such as aesthetics, biodiversity, and mitigation of flooding.

Imaging spectroscopy [4], also known as hyperspectral imaging, is concerned with the measurement, analysis, and interpretation of spectra acquired from a given scene (or specific object) at a short, medium or long distance by an airborne or satellite sensor. Based on the interaction of photons with the molecular structure of the target material, spectral patterns of different mining waste can identify certain compounds, materials.

The special characteristics of hyperspectral datasets pose different processing problems, which must be necessarily tackled under specific mathematical formalisms, such as classification and segmentation or spectral mixture analysis. Airborne Visible Infra-Red Imaging Spectrometer (AVIRIS) scanner data cover now the wavelength region from 0,4 -2,5 μm using more than two hundred spectral channels, at nominal spectral resolution of 10 nm.

Spectral reflectance measurements from the field environment and laboratory samples are needed for many purposes including mineral waste composition as well as for test surface reflectance models. Field spectroradiometers are generally used to collect such data and the technique of field spectroscopy is well established for this purpose [6]. Typically, target measurements are sandwiched between the target and calibrated reference panel measurements in quick succession, typically within 1 min and assume that the irradiance is virtually unchanged.

4. Study test area and data used

Test area Baia Mare (Fig.1) is located in the central-Western area of Maramureş County in Romania, on the middle course of Săsar River.

The topography of the area consists of a paleomorphological structure having the terraces of Someş, Lăpuş and Săsar Rivers in the South and South-

East, and in the North, of the eruptive geomorphologic structures of Igniş and Gutâi Mountains, with a northern area of well-delimited hilly interfluves. Thus, the location of the mountainsides point to the hilly geomorphologic character, with 12% gentle slopes, 73% quick slopes, 13% very quick slopes and 2% steep slopes.

Despite of its location in an attractive natural environment, the utilization of natural resources and the existing polluting mining and metallurgy industries are the main sources of environment (air, water, soil, subsoil, vegetation) degradation water, soil). Maramures County, where is placed Baia Mare is polluted from mining activities which produce acid mine water and waters resulting from ore preparation as well as from industrial activities of non-ferrous ore processing. The major mining waste providers in the Baia Mare area are RBG Phoenix S.A., S.C. Romplumb, the levigation ponds of the plants situated in this perimeter, the mine rock dumps resulting from exploitation activities, and the mine waters discharged from the existing galleries in the area.

The total volume of industrial waste is 1,953,002 tons; out of which 1,148,804 tons (over 90%) is gangue processed with superior technologies for precious and rare metals. Out of the total volume of other industrial waste, the slag resulting from primary and secondary melting in the metallurgical industry is an important source of hazardous waste (18%), only 23.8 % of it being recycled. This slag is quite rich in metals heavy in oxides, which are nevertheless harmless in surface waters or in the atmosphere. Toxic and hazardous waste is a special category of industrial waste. Thus, of 98,480 tons in 1999, 78% is made up of lead accumulators. This waste containing lead is collected and temporarily deposited with a view to recycling it, but the recycling percentage is less than 50%.

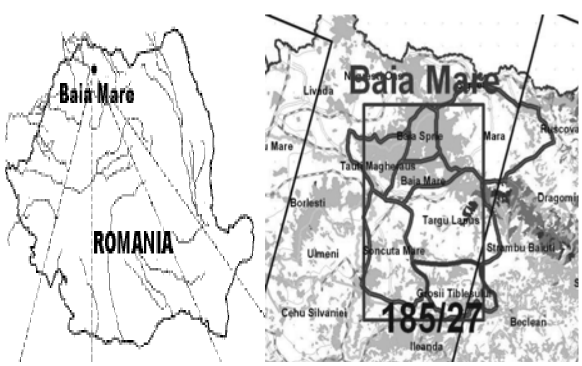

Fig. 1. Test area Baia Mare , North-Western part of Romania.

Have been used several Landsat TM and ETM satellite data over 1989- 2007 period. The investigations were focused on the analysis of satellite data Landsat TM acquired: 3/07/1989, Landsat ETM 22/08/2000; 12/09/2003, ETM 18/08/2007 and IKONOS 06/05/2004.

The images were geometrically corrected to fit a topographic map with a scale of 1:50 000, on which vectors were digitized for the subsequent geocoding of the satellite images. Image processing was performed with ENVI 4.6 and IDL 6.3 softwares and ILWIS 3.1.

5. Results

As a prior step to the environmental study of Baia Mare region and the impact produced by the mining activities, the mining and waste-tip areas were defined and a litho logical discrimination carried out. All the available information on the study area were integrated in a unique database: thematic maps from cartography, land use map from classification of remotely sensed data.

For this purpose, various remote-sensing techniques were employed to create high-resolution image documents on which the geological and environmental mapping of the area would be based, with special attention being paid to the areas of mining industry activity because of its implications for the local environment. The merging of remote-sensing images with different spatial/spectral resolutions has become a highly useful tool, due to their increasing availability.

In order to identify mining waste areas from different sources of remote sensing images, as effective method was used digital image processing (PCA -Principal Components Analysis, Tasseled Cap Transformation, filtering and texture statistics) approaches have been used for information enhancement and feature extraction related to Baia Mare area.

Land cover classification followed a three-step process: (1) ISODATA clustering, followed by (2) identification of potential mining waste areas and creation of a "potential mined-areas mask," and (3) implementation of a decision tree using the mined-areas mask and class transition. The waste mined-areas mask was constructed using ancillary data (mine permits) and the basic land cover classifications to first label as potential mines all pixels falling within the mine permit boundaries. Although the permit areas usually align with known OH bearing minerals and iron oxides seams, the entire permitted area often is not mined completely if no mineral waste is present in some areas. Remote sensing becomes a useful tool to map differences between areas of potential and actual mine waste tailings. In addition, areas not within permit boundaries are also sometimes mineral waste mined. As such, the area of potential mine waste deposits was expanded by including areas outside the permit boundaries that exhibited: (1) single-date NDVI values more than three standard deviations below the mean NDVI; (2) NDVI difference values between two consecutive dates that decreased by more than three standard deviations below the mean NDVI difference; and (3) class transitions (a) from or to Bare/Urban; and (b) from Forest to Pasture on two consecutive dates. This processing step identified mine waste that were not in the mine waste permit data, but clearly could be identified as strip mines from aerial photography.

The results show that remote sensing multi-spectral images have great potentials in large scale mining waste disposal investigation.

The fusion of high-resolution panchromatic and low-resolution multispectral satellite images is a very important issue for many remote sensing and mapping applications. It is the aim of image fusion to integrate image data recorded at different resolutions or by different sensors in order to obtain more information than can be derived from a single image alone[7].

Many situations in remote sensing require simultaneously high spatial and high spectral resolution in a single image. By combining or fusing images it may be possible to obtain both high spatial and spectral resolution in a single display. The benefit of image fusion has been demonstrated in many practical geological applications. A variety of image fusion methods have been developed in the past two decades .The existing can be grouped image fusion techniques into two classes: (1) color related techniques such as intensity–hue–saturation (IHS) and hue–saturation-value (HSV) fusion methods; and (2) statistical/numerical methods such as principal components analysis (PCA), high pass filtering (HPF), Brovey transform (BT), regression variable substitution (RVS), and wavelet methods. After other authors [8], fusion methods were classifieds into three groups: the projection and substitution methods, the relative spectral contribution methods, and those relevant to the ARSIS (acronym for the French: “Amelioration de la Résolution Spatiale par Injection de Structures”, which means “spatial resolution enhancement by injection of structures”) concept. There are also some hybrid methods [9], [10].

Landsat TM, ETM satellite data over 1989- 2007 period provided the opportunity to screen and map in Baia Mare region both surface mine waste and mine reclamation, as well as to estimate the time since reclamation based on the temporal trajectory of land cover. This is important to identify changes in the impacts of mining waste and reclamation on hydrology through time, especially if reclaimed areas show gradual increases in infiltration as vegetation and soil develop. It is possible that indices derived from Landsat TM, ETM multispectral data (Normalized Vegetation Indices -NDVI) and long time series of remote sensing imagery from Landsat to detect land cover changes. Accuracy of image processing results (mineralogical classification) was confirmed through ground sampling and analysis with portable GER 2600 spectroradiometer. These have been analyzed on the basis of absorption band position and shape, and classified on the basis of recurrent associations of absorption bands. Spectroscopic criteria are widely applied in hyperspectral image analysis for mineral and alteration identification and mapping. The image spectra represent the ground reflectance estimated in six channels (the satellite TM bands), respectively at: 0.485 μm (TM1), 0.56 μm (TM2), 0.66 μm (TM3) – the visible part of the elctromagnetic spectrum, 0.83 μm (TM4), 1.65 μm (TM5) – the near infrared and 2.215 μm (TM7) – the short wave infrared.

By analysis of the reflectance spectra of several mining waste samples in the visible (VIS-SWIR) short-wave infrared interval 0,35 μm - 2,5 μm, was examined the feasibility of using detailed spectral information for recognizing the mining waste environment. In some areas have been identified spectral patterns of iron oxides and heavy metals (Fig.3) presents in mining waste minerals as well as hydroxides (Fig.4). Also, have been analyzed the results of this characterization process and implications for environmental impacts and further remediation.

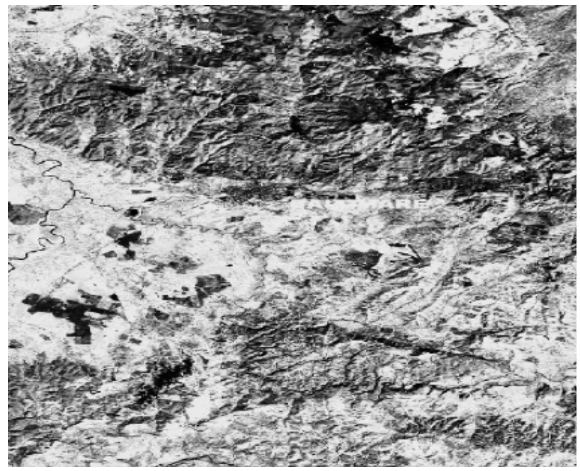

Fig. 2. PCA (4/5/3) analysis for Baia Mare mining area on satellite Landsat ETM 22/08/2000 image.

Land cover/Land use Change map of Maramures County derived from Landsat ETM 22/08/2000 and 18/08/2007 is presented in Fig.5.

Remote sensing techniques were used in order to detect, map and characterize the mineralogical structures of Baia Mare area. Landsat TM, ETM data were use to identify specific features by visual interpretation. Different land cover/land use units were differentiated by several Landsat TM, ETM RGB- processing.

The wastes and tailings in Baia Mare area are often associated with heavy metals, acid mine drainage, and other physical hazards. Many tools have been utilized and proposed for the rapid inventory and characterization of the gross mineralogy of these wastes including the use of Landsat Thematic and Enhanced Thematic Mapper images.

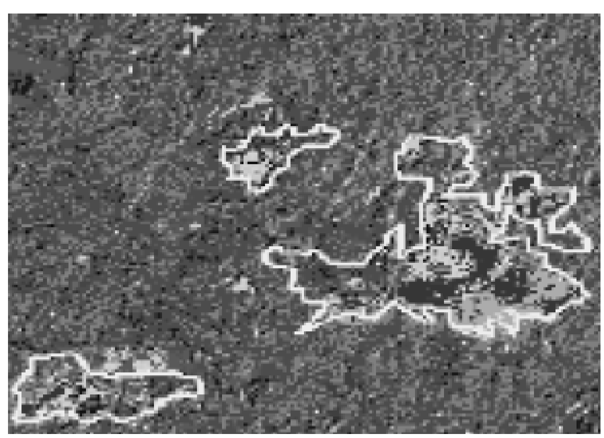

Fig.3. Iron oxide minerals on Landsat ETM image18/08/2007.

False color TM composites were used to perform supervised and unsupervised land cover classifications of Baia Mare test area to identify the locations of mining waste and tailings. In addition, several TM and ETM band combinations (mineral indices) were used to characterize the mineralogy of these wastes. The accuracy of the classifications in identifying mining wastes from other land types was less than 75 percent.

The key to understand the mining waste distribution in mineral industry areas is to integrate satellite observations at local, regional and global scales, over a broad portion of the electromagnetic spectrum with increasingly refined spectral resolution, spatial resolution and over time scales that encompass phenomenological lifecycles with requisite sampling frequency. Recent advances in computational science and numerical simulations are allowing the study of correlated systems, recognition of subtle patterns in large data volumes, and are speeding up the time necessary to study long-term processes using observational data for constraints and validation.

Fig. 4.OH bearing minerals on Landsat ETM image18/08/2007.

Integrating remotely sensed data into predictive models requires measurements at resolutions substantially superior to those made in the past when the observational systems and the discipline of mining waste natural hazards research were less mature than they are today.

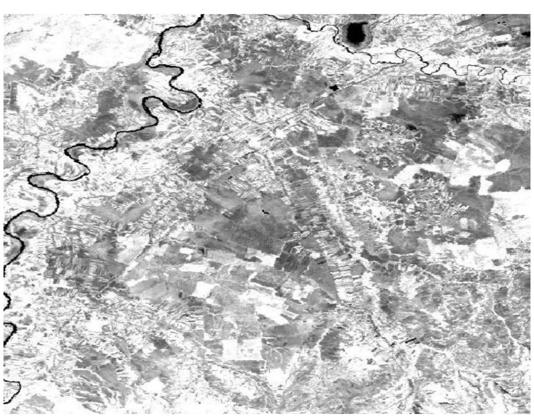

Fig. 5. Land cover/Land use Change map of Maramures County derived from Landsat ETM 22/08/2000 and 18/08/2007.

Furthermore, assimilation of data and model outputs into decision support systems must meet operational requirements for accuracy, spatial coverage and timeliness in order to have positive impact on possible mining disaster risk management.

6. Conclusions

By producing large quantities of mine waste, mining for mineral resources in Baia Mare region and Maramures County, Romania, can seriously alter the composition of the natural landscape, disrupting land use and drainage patterns, contaminating soil and water resources, and affecting habitats for wildlife. Several mine accidents in the area have brought back to the attention of the media, public and decision-makers the problem of potential emissions from metal mining sites, highlighting the priority of prevention as opposed to aftercare. The understanding of the full range of pressures due to emission sources as the result of exploitation of metal mineral resources and abandoned mines can be achieved through compilation of the inventories, the assessment of the environment quality threatened by emissions originating from mining, as well as the evaluation of impacts on the environment through the degradation of the ecosystems, quality of life, including human health, cultural resources, recreational value. The screening by satellite remote sensing and imaging spectroscopy and ranking of all the pressures should be scientifically linked to the impact assessment and prevention of air, water, and soil and vegetation pollution from mine waste in Maramures County. Scientific achievement must be done through combining existing GIS inventory data with remote sensing applications and site assessment based on geo-environmental information.

The utilization of natural resources in Maramures County, Romania and the rigorous pollution control of metal mining industry and waste are priorities with major impact on the strategy and the action plans. Management of mining industries areas at landscape scales means projecting and evaluating interactions and cumulative impacts on many resources at a time. It requires an integration of observational data, science, practice, management experience. Integrated monitoring systems requires both a synoptic view of the mining waste areas to identify broad land cover patterns and a concurrent detailed view of specific locations to allow description and quantification of the type and extent of change occurring at the local level. Satellite remote sensing is becoming an increasingly important tool for advancing research of environmental processes, conditions, and changes due to mining waste for both human and ecological health.

References

[1] W. L. Graf, New Mexico. Ann. Assoc. Am. Geogr. **80**, 327 (1990).
[2] K. A. Hudson-Edwards, M. G. Macklin, J. R. Miller,

P. J. Lechler, Bolivia. J. Geochem. Explor. **72**, 229 (2001).
[3] K. A. Hudson-Edwards, M. G. Macklin, H. E. Jamieson, P. A. Brewer, T. J. Coulthard, A. J. Howard, J. N. Turner, Spain.Appl. Geochem. **18**, 221 (2003).
[4] M. G. Macklin, P. A. Brewer, D. Balteanu, .J. Coulthard, B. Driga, A. J. Howard, S. Zaharia, Romania Appl. Geochem. **18**, 241 (2003).
[5] http://ec.europa.eu/environment/waste/mining/index.htm
[6] B. Lang,O. Edelstein, G. Steinitz, M. Kovacs, S. Halga, Economic Geology and the Bulletin of the Society of Economic Geologists, **89**, 174 (1994).
[7] N. J. Cook, In J. Pasava, B. Krıbek, K. Zak, (Eds.), Proceedings of the Third Biennial SGA Meeting, Prague, Czech Republic, A. A. Balkema: Rotterdam, 851, 1995.
[8] G. Bird , M. G. Macklin, P. A. Brewer, S. Zaharia ,D. Balteanu, B. Driga, Environ. Geochem Health DOI 10.1007/s10653-009-9259-0, 2009
[9] M. S.Moran , R. D. Jackson, P. N. Slater, P. M. Teillet, Remote Sensing of Environment **41**, 169 (1992).
[10] S. Song, C. E. Woodcock, K. C. Seto, M. Pax-Lenney, S. A. Macomber, Remote Sensing of Environment **75**, 230 (2001).

*Corresponding author: mzoran@inoe.inoe.ro