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SHORT NOTE

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Mine Wastes Environmental Impact Mapping Using Landsat ETM+ and SPOT 5 Data Fusion in the North of Tunisia

Nouha Mezned[1] · Nada Mechrgui[1] · Sâadi Abdeljaouad[1]

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Abstract Mine wastes constitute an alarming source of pollution that threatens soils, vegetation and human health around Jebel Hallouf-Bouaouane mine site. Because of their widespread geographical distribution; their location and extent, the characterization of mine wastes using traditional field work alone is both costly and inefficient. In this study, we explore remote sensing techniques based on multispectral and multisensor data fusion. Our contribution consists in enhanced mine wastes map for environmental impact detection using both SPOT 5 (Satellite Pour l' Observation de la Terre 5) panchromatic (Pan) and Landsat Enhanced Thematic Mapper Plus ETM+ multispectral (MS) data. The linear spectral unmixing of the hybrid image show results with respect to the field truth. The inter-comparison of maps indicates that this methodology can be applied successfully to multispectral data for multi-temporal monitoring of mine wastes.

Keywords Mine wastes · Environmental impact · Spot 5 · Landsat ETM+ · Data fusion · Spectral unmixing

Introduction

One of the major environmental problems resulting from the mine activity is the pollution of soils and vegetation with wastes left over after ore processing in mining operations. Nowadays, these waste products constitute an alarming source of pollution that threatens human health. Moreover, physical hazards such as subsidence and wastes dam failures may also occur (Slim 1981; Mansouri 1980). Thus, monitoring the environmental risks associated with mine wastes in a quick and timely fashion is the first step towards mitigating their impact. Because of their widespread geographical distribution; their location and extent, the characterization of mine wastes using traditional field work alone is both costly and inefficient. Remote sensing techniques have been proven extremely valuable in the inventory, characterization, and remediation of mine wastes elsewhere.

For remote sensing applications, both high spatial resolution and high spectral resolution are often desired to achieve more detailed and more accurate information acquisition. Therefore, the need for effective fusion of Pan and MS images (also called pansharpening) is tremendous to improve information extraction. In many remote sensing and mapping applications, the fusion of high-spectral but low spatial resolution multispectral and low-spectral but high spatial resolution panchromatic satellite images is a very important issue. Many image fusion techniques and software tools have been developed. The well-known methods are, for example, the IHS (Intensity, Hue, Saturation), PCA (Principal Components Analysis), arithmetic combination based fusion, and wavelet based fusion (Chavez et al. 1991; Ranchin and Wald 2000; Shi et al. 2003; Otazu et al. 2005; Eshtehardi et al. 2007). Most techniques have been developed based on the fusion of the SPOT pan with other multispectral images, such as Lansat TM and SPOT HRV XS. If the objective of image fusion is to construct synthetic images that are closer to the reality they represent, then, according to the criteria proposed by Wald et al. (1997), IHS and PCA fusion methods meet this objective (Ranchin and Wald 2000). These techniques have received tremendous attention in the remote sensing literature and have been well applied for land surface detection and mapping

✉ Nouha Mezned
mezned_nouha@yahoo.fr

1 Laboratoire des Ressources Minérales et Environnement, Faculté des Sciences, Université Tunis El Manar, Campus Universitaire du Belvédère, 1092 Tunis, Tunisia

(Munechika et al. 1993; Peters et al. 1996; Zhang 2004; Nichol and Wong 2005; Amolins et al. 2007: Mezned et al. 2012).

In this study, we explore the mine wastes mapping with remote sensing techniques for specific mine in a semi-arid context in Tunisia. We give a detailed spatial distribution map of the mine wastes, in the test site. The adopted methodology was based on multispectral and multisensor data fusion techniques. Our contribution consists in enhanced mine wastes map with respect to multisensor multispectral data fusion. We operate the procedure using both SPOT 5 panchromatic and Landsat ETM+ multispectral multitemporal data. The linear spectral unmixing method allows an optimal exploration of the resulting hybrid image. Results were validated using High spatial resolution image as well as ground truth. The inter-comparison of unmixing results indicates that this methodology can be applied successfully to multispectral data for multi-temporal monitoring of mine wastes.

Materials and Methods

Study Site

Mine wastes are an alarming problem in the Jebel Hallouf-Bouaouane mine (Fig. 1), located in the upper river of Mejerda (3642′N 90′5″E) and which was exploited for the lead and zinc ores. The mining and smelting of these ores has left over an important quantity of mine wastes containing elevated levels of lead, cadmium, zinc, and other metals (Slim 1981; Mansouri 1980). These wastes, threat soils (through metal-contamination), local vegetation, ground water and water quality. Determining the geochemistry and above all location and extent of mine wastes is the first step towards remediation and hence avoidance of negative health and environmental consequences.

Methodology

The methodology proposed in this study was applied using multispectral multisensory data. Particularly, we have used Landsat ETM+ and SPOT 5 data. ETM+ sensor on board the Landsat 7 satellite was launched in April 1999 for land observation. It provides 7 bands of multi-spectral data at 30 meters resolution, plus a panchromatic band at 15 m, over a swath 183 km wide. There is also a 60 m thermal infrared band. The used Landsat ETM+ image data ("National Land Archive Production System" NLAPS L 1 G Products) were acquired over the study site on May 1, 2005 and March 17, 2012 with 28.5×28.5 m spatial resolution. All 7 bands between 0.45 and 12.5 μm were used except the thermal band 6 due to its coarse resolution. The SPOT system has been operational since 1986 when SPOT1 was launched from Kourou spatial base. SPOT 2 was placed in orbit in January 1990, followed by SPOT 3 in September 1993, SPOT 4 in March 1998 and SPOT 5 in May 2002. The used SPOT 5

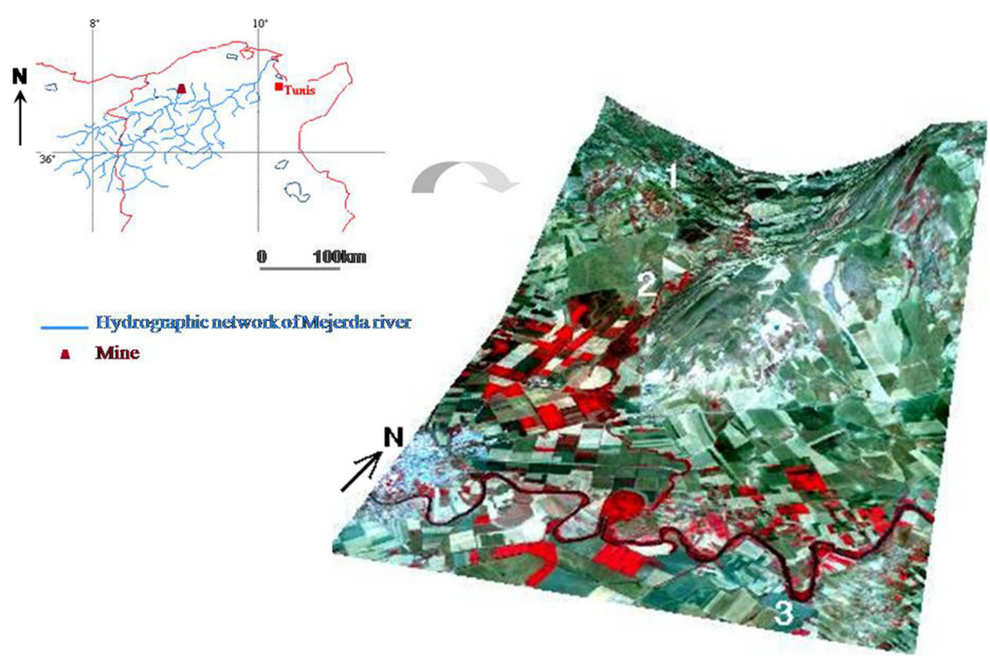


Fig. 1 Map showing the location of the Jebel Hallouf-Bouaouane mine in the Medjerda river watershed (a) and the corresponding 3D till representation mapped with a Landsat imagery (60×100 pixels) to the study site (b). The white numerous indicate location of the mine wastes (1), Kassab wad (2) and Medjerda river (3)

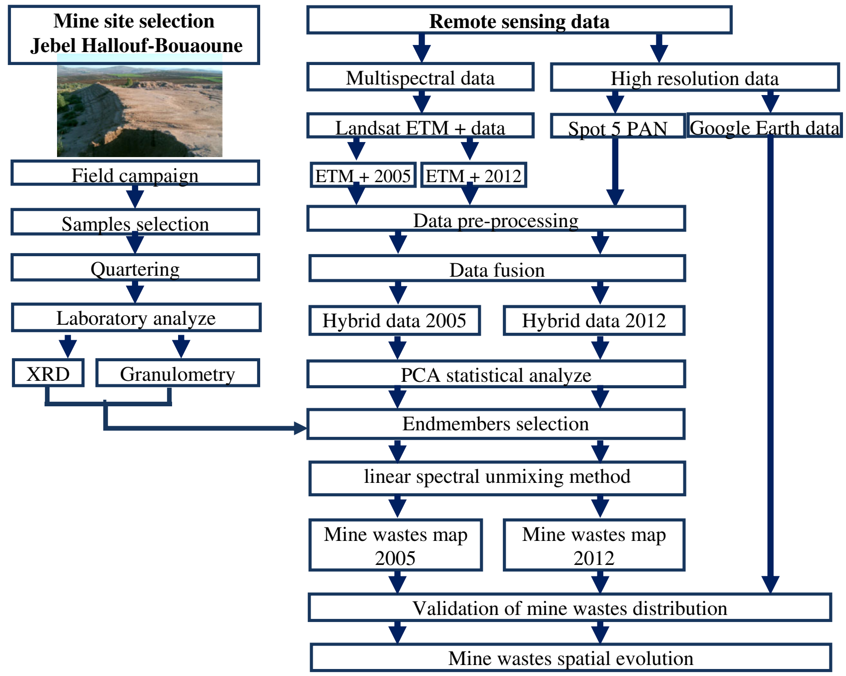


Fig. 2 Methodology flowchart

panchromatic image data was acquired on May 3, 2004 with 2.5 × 2.5 m spatial resolution.

The complete processing of the Landsat ETM+ Surface Reflectance and SPOT 5 data for the enhancement of wastes maps is illustrated by the flowchart on Fig. 2. It includes two main parts: the first one deal with the multispectral Landsat ETM+ and panchromatic SPOT 5 image fusion based on Principal Component (PC) Spectral Sharpening method. The resulting Hybrid image presents an optimal spatial resolution. The second part, focus on the classification and inter-comparison of mapped hybrid images. Panchromatic (Pan) SPOT and multispectral ETM+ data were geometrically and atmospherically corrected before they are combined and fused. The radiometric and atmospheric correction were performed using the "Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes" FLAASH model to estimate the spectral reflectance surface. An overview of this methodology is presented in (Cooley et al. 2002).

Constrained linear unmixing algorithm was after that processed on both resulting multi-temporal hybrid data to generate spatial detailed wastes maps. Spectral unmixing is a quantitative analysis procedure used to recognize constituent ground cover materials or endmember and obtain their mixing proportions from a mixed pixel (Tompkins et al. 1997). In our study we applied the constrained linear mixture model:

$$\sum_{i}^{p} a_i = 1$$

$$a_i \rangle \ 0$$

Where:

a $(a_1; a_2; :::; a_p)$ is the ground abundance fraction in ground samples

p is the number of endmembers.

The method can not only gives the endmembers distribution, but also get the abundance images of surface cover types constituting the area of a pixel. The classification was based on statistical principal component analysis PCA for judicious endmember selection. Mine wastes fraction maps were validated using high spatial image and terrain truth. The inter-comparison

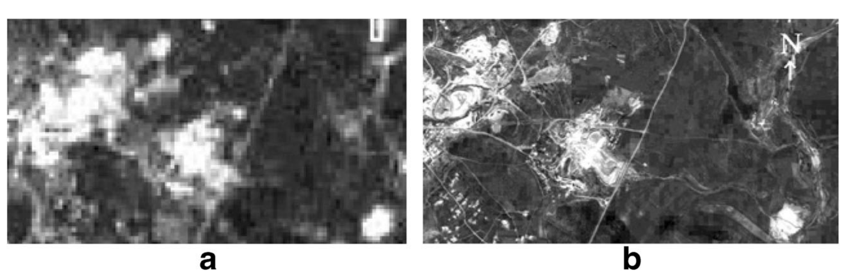


Fig. 3 Image Landsat ETM+ acquired on March 17, 2012 on Jebel Hallouf-Bouaouane mine: (**a**) before and (**b**) after fusion with SPOT 5 PAN imagery

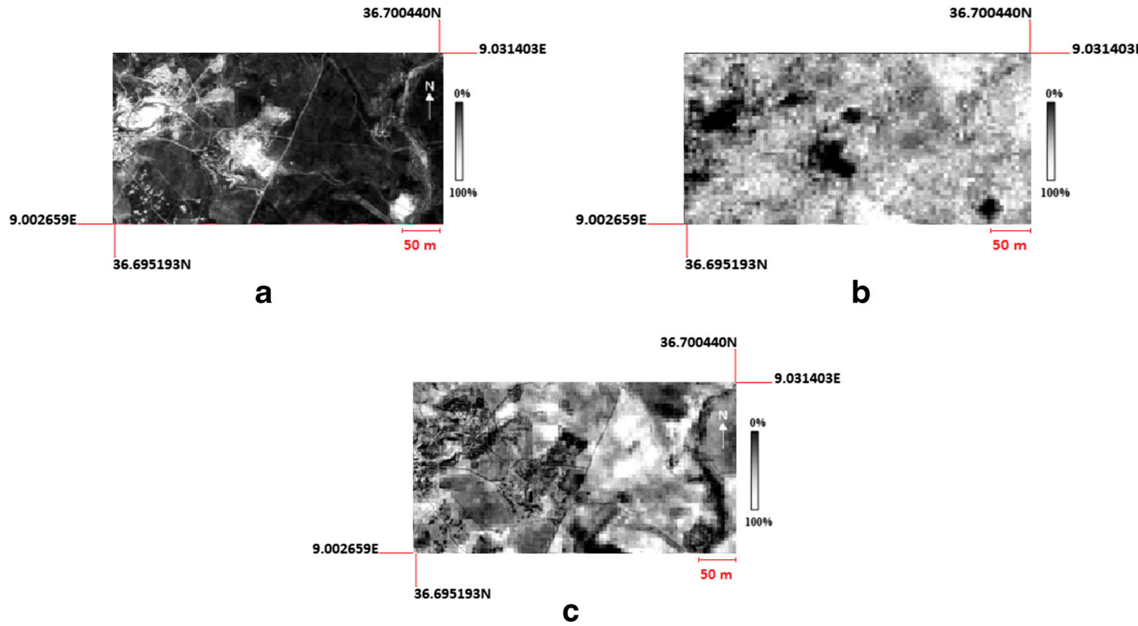


Fig. 4 Maps (1050 * 560 pixels) showing the spatial distribution of: (**a**) tailings (**b**) soils and (**c**) vegetation, resulting from constrained linear spectral unmixing of hybrid image acquired on 2012

of both tailing fraction maps allowed the multi-temporal monitoring of tailings around Jebel Hallouf-Bouaouane site.

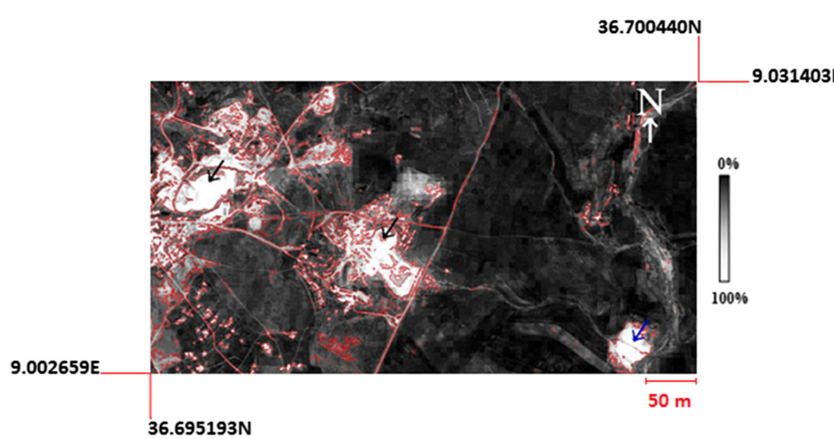
Results and Discussion

Results are given as a comparison of fraction maps showing the distribution and the abundance of the principal endmember existing in the mine site. Both resulting hybrid images (Fig. 3) have the high spatial resolution of the (Pan) SPOT 5 image (2.5 m) and the relative high spectral resolution of ETM+ image (6 bands) (Mezned et al. 2014).

Both Hybrid images classification is performed with the spectral unmixing method. It was performed using the image derived endmember spectra. Endmembers were selected from the both images using the first three principal components (PC) which respectively account for 80.92, 97.39 and 99.10 % of the variability in the data set acquired on 2012. It account for 80.40, 96.72 and 99.05 % of the variability in the data set acquired on 2005. Three endmembers could be identified using the first three PCs in both cases (Fig. 4). The used endmembers are identified as mine wastes, soils and vegetation. The unmixing results conducted on both Hybrid images, show different fraction maps. This method provides the absolute abundance and the RMS errors. Thus, the accuracy of estimated endmember proportions is evaluated according to the RMS errors. The most of RMS errors (87 %) are lower than 0.11 and 0.19 for respectively the classification of Hybrid data of 2012 and 2005. It shows good results.

Endmember fraction maps show their distribution variability in the mine area. Note that a white (respectively, black) pixel in the map indicates a large (respectively, small) value of the abundance estimation. Mine wastes (represented by white

Fig. 5 Map (1050 * 560 pixels) showing tailing inter-comparison distribution between both wastes maps of 2012 (*red line*) and 2005



pixels in dikes and alluvium area) can be clearly recovered (Fig. 4a). It is of considered interest due to the important quantity of wastes. Moreover, the influence of hydrous and wind erosion, as well as topographic factor, is better showed than in (Mezned et al. 2012).

Likewise, a second set of fraction images were produced using the second Hybrid image, acquired on May, 1 2005. The classification results show a similar tailing distribution as in the first map (2012). However, some differences are detected in the eroded and transported wastes near Kassab wad.

Furthermore, the comparison of the spatial distribution and abundances of wastes, estimated from both classifications, show some differences (Fig. 5). Indeed, although the matrix is carbonated, wastes trends under the impact of climatic and topographical factors were highlighted during this period. Inter-comparison of enhanced multitemporal maps allowed better impact detection and monitoring of wastes around mine site. These results show an interesting contribution of hybrid images for enhanced mine wastes detection in Jebel Hallouf-Bouaouane for both acquisition date.

Conclusions

In this paper, an enhanced mine wastes mapping is presented using both SPOT 5 panchromatic and Landsat ETM+ multispectral data. Experimental results show that the wastes mapping accuracy has dramatically improved by effective image fusion of Landsat ETM+ MS and SPOT 5 Pan data. The linear spectral unmixing of both hybrid data, shows accurate wastes distribution maps with respect to ground truth. Moreover, the inter-comparison of results indicates that this methodology can be applied successfully to multispectral data for multitemporal impact detection and monitoring of mine wastes.

To generate detailed wastes maps; we propose in the future an approach based on the use of hyperspectral data. Since the satellite data show low spatial resolution, image fusion technique seems to be an optimal solution to overcome this limit. Moreover, the use of field spectra will improve results.

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