APPLYING SPECTRAL UNMIXING TO DETERMINE SURFACE WATER PARAMETERS IN MINING ENVIRONMENT

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ABSTRACT

Water has been traditionally monitored by *in situ* measurements taking point samples at regular intervals. From an optical perspective, in addition to pure water itself, the optical properties of surface waters are mainly influenced by three constituents: phytoplankton, suspended sediment, and coloured dissolved organic matter (CDOM). Although imaging spectroscopy can serve as a modern method to monitor polluted surface waters, only a limited number of studies have been published on this topic. In our study, we tested the feasibility of mapping the properties of surface waters affected by long-term mining activities using airborne multi-flight-line HyMap hyperspectral (HS) datasets. An approach using fundamental water image end-members to map relative abundances of selected parameters of surface waters (dissolved Fe, dissolved organic carbon DOC, non-dissolved particles) was tested and ground truth (eight monitored ponds) was then used to validate the results of spectral mapping. Although the detected end-members did not implicitly have to be absolutely pure, they represented the most extreme water types within the studied area. Correlations between the studied water parameters and three fractional images were detected (dissolved Fe: R^2=0.74, undissolved particles: R^2=0.57, DOC: R^2=0.42); these images were further used to create semi-automatic maps.

INTRODUCTION

Water has been traditionally monitored by *in situ* measurements taking point samples at regular intervals. However, point samples are not adequate to observe spatial and temporal variations in large areas or in polluted regions where the water quality can change dramatically and needs to be monitored at a regular basis. From an optical perspective, in addition to pure water itself, the optical properties of surface bodies of water are mainly influenced by three constituents: phytoplankton, suspended sediment, and coloured dissolved organic matter (CDOM) that is also called yellow substance or gelbstoff. Although imaging spectroscopy can serve as a modern method to monitor polluted surface waters, only few studies have been published on this topic (1,2,3,4,5).

In our study, we tested the feasibility of mapping the properties of surface waters affected by long-term mining activities using airborne multi-flight-line HyMap hyperspectral (HS) datasets. The work was carried on the Sokolov lignite mines as they represent a site with extreme dynamics, material heterogeneity, high pH gradients and wide varieties of surface water pollution. Unfortunately, only limited ground truth data collected at the time of HS data acquisition were available. Moreover, it was not possible to collect any field spectroscopic data on waters at that time; therefore either empirical (e.g., 6) or physical modelling (e.g., 7) could not be applied. Instead, an approach using fundamental water image end-members to map relative abundances of selected parameters of surface waters (dissolved Fe, dissolved organic carbon DOC, non-dissolved particles) was tested and the ground truth (eight monitored ponds) was then used to validate results of spectral mapping.

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METHODS

Site description

The study was performed in the Sokolov basin in the Western part of the Czech Republic, in a region affected by long-term extensive lignite mining (Figure 1). Due to the presence of S in the coal, the lignite mines both still active and abandoned, are largely affected by acid mine drainage (AMD) (8,9). In 2009, diverse abandoned pits and dumps together with still-operating mines could be found within the Sokolov basin. Diverse anthropogenic substrates as well as lower seated lithologies of the basin had been exposed and artificial ponds which differed in chemical and physical properties were possible to investigate in 2009.

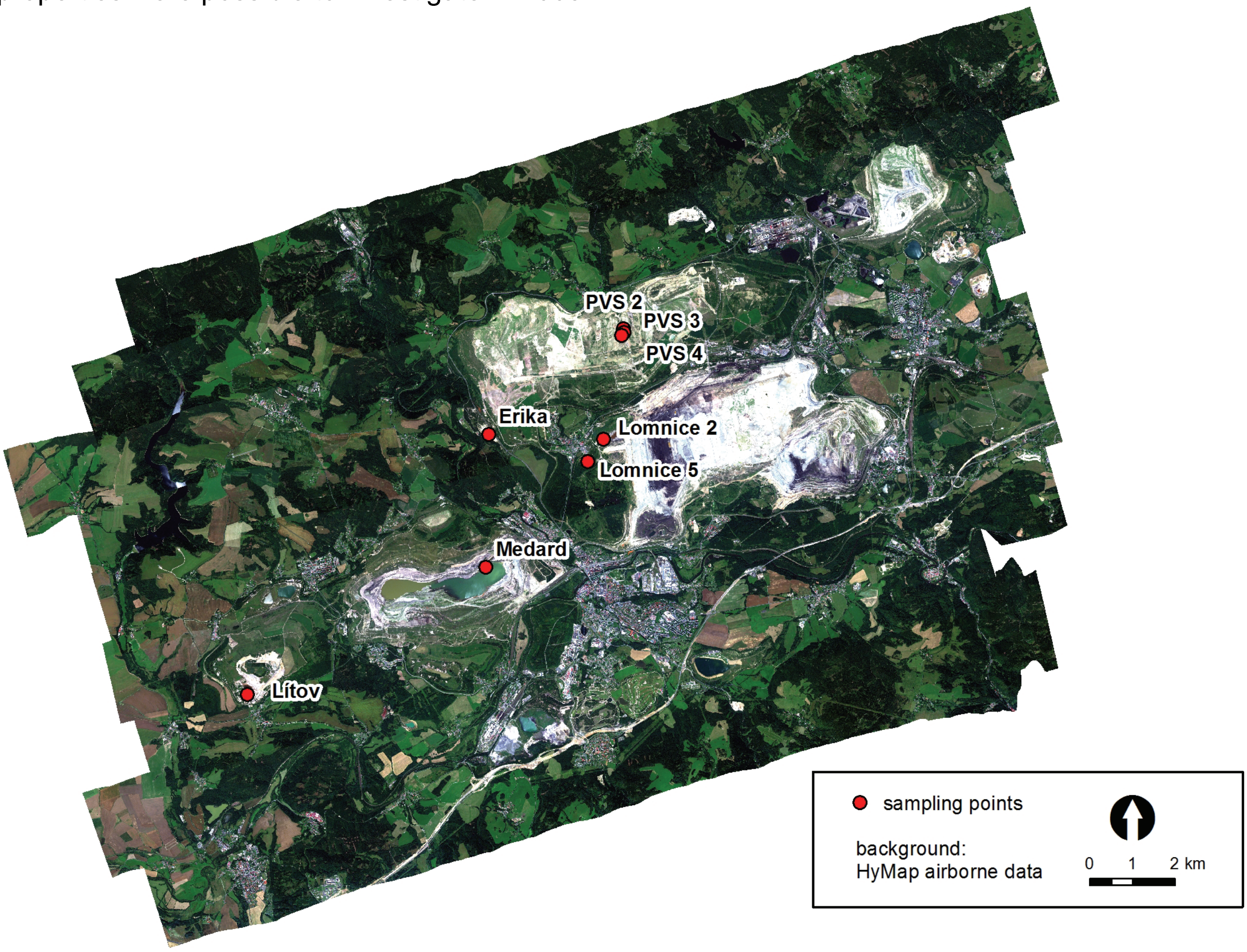

Figure 1: Test site and sampling/measuring points displayed on the HyMap 2009 data (corrected reflectance, true colour coding).

Data

The 2009 HyMap multiple flight line data were atmospherically corrected using the software (SW) package ATCOR-4 version 5.0. In addition to the atmospheric correction, the 2009 reflectance data had to be further processed to minimise the Bidirectional Reflectance Distribution Function (*BRDF*) effect employing semi-empirical nadir normalisation using the kernel-based Ross-Li model for all flight lines. Finally, the hyperspectral image data were ortho-rectified using the PARGE software and georeferenced to the UTM 33N (WGS-84) coordinate system.

One week after the flight campaign, a field trip was organized to investigate general chemical and physical properties of the Sokolov surface waters. Seventeen water sites were selected where the pH, Eh and temperature were determined using a field pH-Eh meter (pH/Cond 340i) on site. To resolve other parameters (DOC, dissolved Fe, non-dissolved particles) water samples were collected following standards required by the certified laboratories of the Czech Geological Survey.

The samples were immediately put to a cooler and afterwards to the fridge, where they stayed till they were transported to the laboratories.

Spectral mapping methods

Image end-members were derived from the HyMap 2009 data and used for further image processing. The method consisting of the minimum noise fraction transformation (*MNF*) and pixel purity index (*PPI*) procedures was employed to select the 'pure' image end members (Figure 3C). In this routine, the image data are subjected to spectral and spatial reduction in order to identify the end members of spectrally unique pixels which are assumed to be the most pure pixels. We assume that a spectrum of all the fundamental water types differing in chemical composition and physical properties can be derived from a hyperspectral image data by applying this procedure. To relatively estimate the selected end-member abundances it was highly desirable to use a sub-pixel method rather than a hard classifier. Therefore, we took advantage of the linear spectral unmixing (*LSU*) method (10), as it allows sub-components of the spectrum to be identified and the abundance of different materials to be determined for each pixel. Spectral mixture analysis is also based on the principle that the reflectance recorded for each pixel within an image is a combination of the reflectance from all pure end members found in that image. Although the image-derived end-members do not necessarily have to be pure, our analysis is based on the assumption that linear mixing is a sufficient first-order approximation to constrain the relative abundances.

Correlation analysis was employed between the collected ground truth data (water samples taken for the eight water bodied big enough to be resolved under a 5 m pixel size of the HyMap data) and fractional images, the results of *LSU*, to find the fractional images with statistically significant correlations; those were further studied and utilized for spatial mapping (Figure 2).

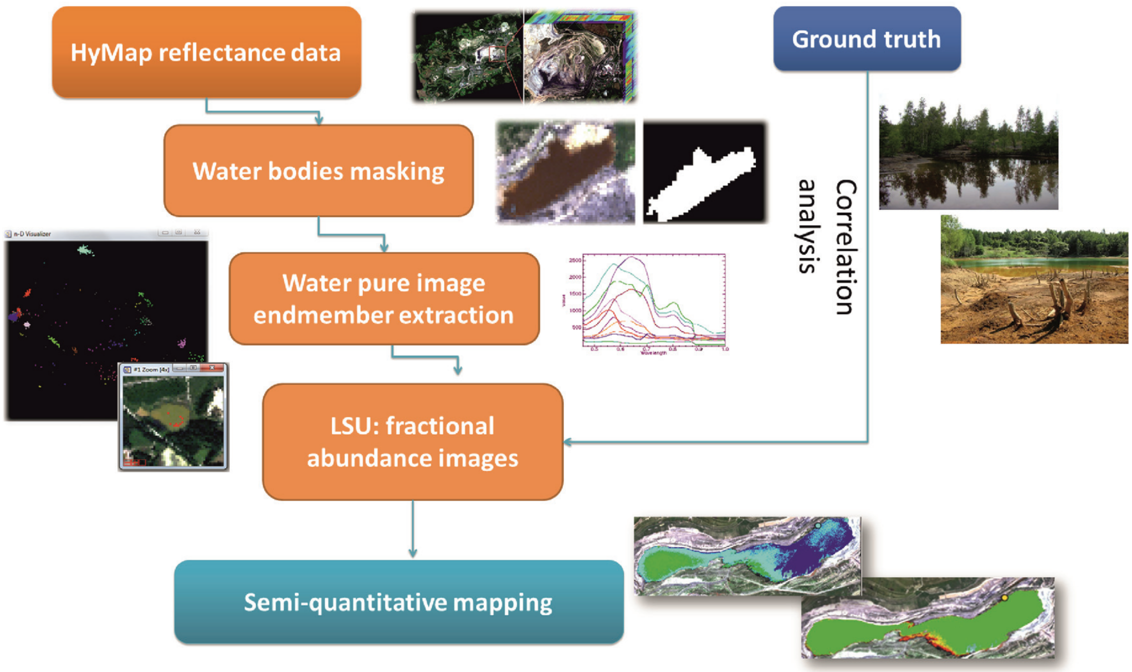

Figure 2: The processing scheme.

RESULTS

Correlations between the studied water parameters (DOC, dissolved Fe and non-dissolved particles) and fractional images (the results from LSU) were calculated. A fractional image with the highest correlation was then selected for each parameter (Table 1) and a spectral property of a corresponding end-member (Figure 3C) was studied and compared with the literature. The DOC end-member reflects light in the red (NIR) region and exhibits a reflectance peak at 650 nm. This shows that in the case of Sokolov waters DOC is present together with tripton and the reflectance property can be explained by a combination of scattering from tripton (high red reflectance, maximum at 670 nm) and selective absorption by DOC at short wavelength (blue wavelengths: 450-500 nm) (11). Similarly, increasing DOC with increasing peak wavelength toward the red wavelengths was also reported by (12), while a water group with higher DOC concentrations (4.6 - 9.2 ppm) had higher peak wavelengths ranging from 671.9 to 695.8 nm. The end-member derived for non-dissolved particles exhibits two reflectance peaks, the most visible at 550 nm and the second peak at 810 nm. This is in accordance with (13,6), as high reflectance in the green (560 nm) and red region (700 nm) was found for sediment-dominated waters. The end-member representing waters with high dissolved Fe content exhibits the same spectral property as described by (1) and (2). The reflectance is reduced and the peak wavelength is shifted to the red region. The strongest correlation was found between the fractional image and dissolved Fe, the weakest between the fractional image and DOC (R^2=0.42). The weaker statistical relationship found for both non-dissolved particles and DOC indicates that they are most probably present in diverse forms.

As the spectral property of the selected end-members was in accordance with previously published results and could be explained on a physical basis, the corresponding fractional abundance images were further used to create semi-automatic maps (Figures 3A and B).

Table 1: Statistics on the linear regressions (water ground truth data and the selected fractional images achieving the highest R^2).

Variable	**R^2**	**Sigma**
Fe dissolved	0.74	0.006
DOC	0.42	0.116
Undissolved particles	0.57	0.031

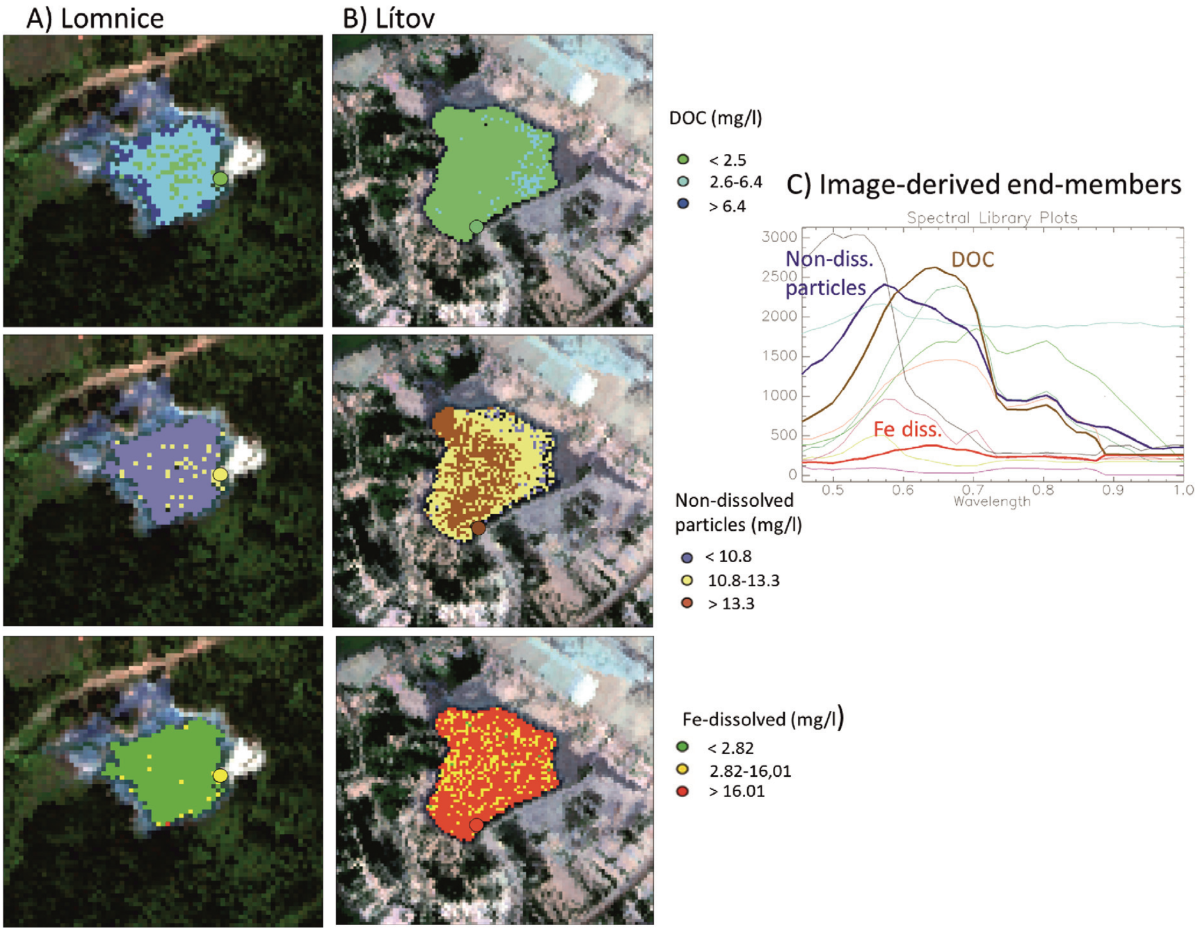

Figure 3: A-B: An example of semi-automatic maps of the two ponds (Lomnice and Litov) monitored in 2009, C: image-derived end-members used for LSU).

CONCLUSIONS

Having a limited number of ground truth data, we demonstrated how the LSU method could be utilized to map selected water parameters at a semi-quantitative level using HyMap image data. A key issue was to find proper pure image end-members for the fundamental water types (water rich in DOC, suspended solids and dissolved Fe). Although the detected end-members did not implicitly have to be absolutely pure, they represented the most extreme water types within the studied area. Correlations between the studied water parameters and three fractional images were detected (Fe dissolved: R^2=0.74, Undissolved particles: R^2=0.57, DOC: R^2=0.42); these images were further used to create semi-automatic maps.

Our study shows that such methods could be used to classify mining waters into basic groups to make water sampling/monitoring more efficient or to support further detailed investigations leading to quantitative spectral mapping. Water sampling can be very time-demanding and costly; therefore this study can have further implications if satellite multispectral/hyperspectral data were utilized for regional studies. Additionally, if temporal changes are studied using multi-data image data, end-members derived from an image acquired under the most extreme weather conditions, when the concentration of the studied parameters is at its highest, could be used to classify the other temporal image data. Considering mining water pollution and how imaging spectroscopy could be used for this issue, only a limited number of papers have been published so far. Therefore, more systematic work to link optical and physical-chemical properties of waters should be done in the future.

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