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Monitoring of hydrochemical parameters of lignite mining lakes in Central Germany using airborne hyperspectral *casi*-scanner data

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ABSTRACT

Active and abandoned coal mines have a huge impact on the environment. The most challenging problem is caused by acid mine drainage (AMD). Using traditional methods such as single point measurements to determine and analyze mining lakes over the period of a few years is difficult due to the lakes' high dynamic and inner differentiation. To overcome this difficulty, a new method has been successfully tested to additionally monitor residual lakes. Using a manifold data set (like images from the hyperspectral airborne scanner *casi,* ground truth data, spectral field and laboratory measurements), the optical properties (reflection, absorption and scattering) of acid mining lakes were defined for the first time ever. Furthermore, hydrochemical parameters in quality and quantity were ascertained in a two-stage process. First, optical properties of the mining lakes were analyzed and defined for each of the limnological stages of development. Second, based on the lakes' optical properties, algorithms for classification of the hydrochemical parameters evolved and were reliably utilized. The new algorithms enable the monitoring of mining lakes from acidic to alkaline as well as the quantification of the hydrochemical properties inside the lake water.

1. Introduction

Mining activities pose some of the greatest environmental challenges worldwide. Increasingly, the environmental impacts of mining activities become an economical and social concern. Remote sensing has mainly been used for exploration of mining sites; however, its rising use in assessment and monitoring of the environmental impacts encourages the planning of recultivation early in the life cycle of a mine. Schmidt and Glaesser (1998) had already performed a monitoring of the environmental impacts of open cast lignite mining in Eastern Germany by using satellite data. In terms of its spectral and spatial resolution, these medium resolution data were not sufficient to detect the influence of acid mine drainage (AMD), which has an effect on the differentiation of the lakes.

Acid mine drainage (AMD) causes significant damage created by the metal mining and coal mining industries (Geller and Schultze, 2009; Geller et al., 1997, 1998). It can influence all land uses, soils and more often the surface and groundwater in a region. AMD is caused by the oxidation of sulfides such as pyrite (Paktunc, 1999; Schultze et al., 2010), which are present in the coal itself and also in the underlying or overburden material. Coal mine drainage is a matter of serious concern (Hellier, 1999). Azcue (1999) gives an overview of well defined case studies around the world. Geochemical and hydrochemical characterizations of mine sites are important for remediation, protecting the surrounding environment and monitoring these sites together with their environment.

As mentioned, metals in mine sites are usually hosted by acid generating sulfide rich minerals. It has been shown, however, that certain sulfide rich minerals, secondary iron bearing sulfates, hydroxides or oxides have indicative spectral features, which enable their detection with hyperspectral data (Crowley et al., 2003; Kemper and Sommer, 2002; Swayze et al., 2000). Ong et al. (2003) were able to successfully detect acid-drainage related minerals using a time series of Hymap data. There are many published papers on the subject of AMD with brief mention of its influence on water quality. For instance, Riaza and Müller (2009) focused on studying river sediments. Fortunately, widespread knowledge exists about the optical properties of inland water and models for qualifying and quantifying these parameters (Dekker, 1993; Gege, 2004; Heege and Fischer, 2004; Heege et al., 2005; Thiemann and Kaufmann, 2002).

The drainage water of many lignite open pits is acidified due to sulfide oxidation. These abandoned mines contain significant quantities of oxidized sedimentary sulfidic minerals. If they are flooded with ascending ground water or surface water, like river water, for instance, there is a great risk the lakes become, at least temporarily, acidic (Klapper and Schultze, 1995; Schultze et al., 2009; Trettin et al., 2007). In addition to all field and analytical research, a detailed monitoring of lake water quantity and moreover water quality is necessary. Hence, the aim of this research was to investigate the potential of hyperspectral airborne image scanner *casi* data as an additional monitoring system of residual lakes.

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2. Area of research

The test site is located in Central Germany near Bitterfeld (Fig. 1). It is a part of the North-West Saxony Tertiary lignite deposit district, which is covered by Quaternary sediments (Eismann, 2002; Schreck and Gläßer, 1998; Schroeter and Gläßer, 2011).

Within the area of interest exist many abandoned mine sites; one of them is the Goitzsche mine site. During the exploration of the lignite and also years later, the ground water had to be lowered to a level under the coal bearing seams. For this reason, the natural aquifers became waterless and subsequently the sulfidic minerals oxidized and Fe^{3+} precipitated (Klapper and Geller, 2001). After the dewatering was stopped, the ground water level rose and the accumulated sediments in the aquifers turned into a solution and led to Fe^{2+}, pyrite oxidation and acidification. The Tertiary material contained iron sulfate and other reductive sulfur compounds. If sediments with high contents of lignite or iron are under anoxic condition, there is a reduction of sulfate and a high potential for acid mine drainage.

The existing residual holes vary in age, geomorphological forms, geochemistry of the dumped sediments, hydrochemical properties, intensity and quality of the arising ground water as well as the time and space of filling with surface water. The Goitzsche mine site represented an instable hydrogeological system, where a high diversity of residual lakes could be investigated in a small area (Knöller et al., 2003). The water quality in these pit lakes varies with the beginning of the flush from highly acidic to alkaline in a very short period. The filling process with surface water of the river Mulde started in May 1999 and ended in the spring of 2002. For more detailed information and visualization on this process see Gläßer et al. (2010) and Thürkow et al. (2009).

With the ongoing process of flooding with surface water, we have to consider an increase in the size of the lakes and a growing influence of the river water quality towards the mine lake water. Especially in the upper part, an exchange between the different lake holes to one large lake may also occur. The development of the lakes indicated that flooding of mine sites with surface water is viable and a good option for neutralization. Erosion and elution of the embankment and the bottom of the former mine site are important factors for the lake water quality. They can also act as a source of acidity as well as alkalinity. This interaction between the embankment and lake water continues over a long period of time. There are many detailed investigations about the hydrological and hydrochemical development of the lakes (Schultze et al., 2002a, 2009; Trettin et al., 2007). However, what is missing from approaches using selective sampling and theoretical modeling is a thorough and comprehensive analysis of the distribution of these properties between and within lakes. The test site is a well investigated area and is also compatible as a case study for development of algorithms which can be used to monitor the AMD influenced waters in other parts of the world. The future usability of the lakes (e.g. for tourism, recreation and fishery) is dependent strongly on the water quality (Klapper and Geller, 2001; Schultze et al., 2010). To observe and monitor this fact over a long term, lake water quality parameters are essential.

3. Objectives

As mentioned above, contrary to acid lake water spectral properties, the basic knowledge about the inherent optical properties of inland lakes are well defined. The objectives of the investigation are detailed with systematic analyses and characterization of these acid

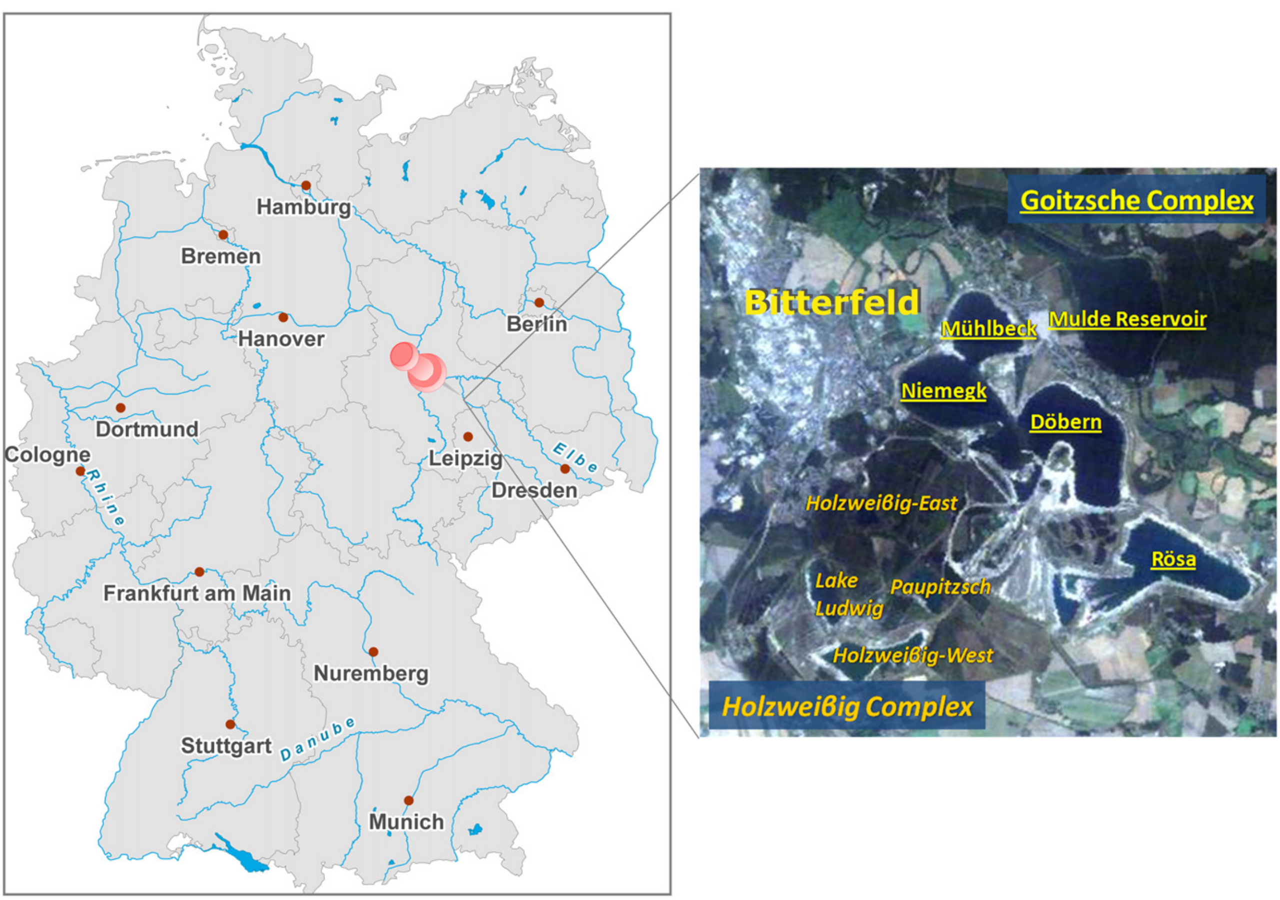

Fig. 1. Overview of the test site Goitzsche, near Bitterfeld, Central Germany.