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Analyses and monitoring of lignite mining lakes in Eastern Germany with spectral signatures of Landsat TM satellite data

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ABSTRACT

Coal mining activities cause an increased acidity and an associated decrease of the pH-value in mine waters. This process is also known as acid mine drainage (AMD). Due to AMD, lakes that were formed in the post mining landscapes in the lignite mining area of Central Germany are characterized by specific limnological development changes. Remote sensing is a time and cost saving technique that enables the observation of the hydrological and limnological development of the lakes ranging from a small to a mid size scale.

The current research was based on Landsat TM5/ETM+7 satellite data collected between 1999 and 2004. In combination of satellite data, surface waters of the post mining lakes in Central Germany were sampled and analyzed for their physicochemical properties. The objective of this approach was to evaluate the environmental conditions and to develop a monitoring system. On the other hand, the research was conducted to assess the potential of the use of satellite data and to calibrate its content for monitoring the geochemistry of mining lakes.

Correlation of hydrochemical parameters of lake water to spectral signatures detected by satellites was performed with multivariate statistical analysis methods. The five determined clusters of spectral partitions described the actual data (ground truth data) within the visible range. The statistically identified clusters were combined with expert knowledge in limnology, geology and water chemistry of large scale lakes in open cast mining areas, in order to analyze the spectral information of the satellite images scientifically. The utilization of spectral signatures revealed an acceptable classification of hydrological and hydrochemical properties of mining lakes and established the basis for further investigation of open cast lignite mining concerning the environmental impact, particularly in areas where lignite mining lakes usually form.

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1. Introduction

Mining activities cause serious impacts on ecosystems worldwide. Therefore, a multidiscipline approach to reduce ecological and economic problems is required for all mining consequences within active and abandoned mines. Information about the temporal and spatial data of different parameters is essential in each phase of mining for the success of both the productivity and for reclamation of the land. Different phases of open cast mining include exploration, excavation and reclamation, as well as the assessment and permanent monitoring of inactive mines. The exploration of raw materials and different phases of mining are often supported by remote sensing activities, which have become popular in recent years.

Although its popularity, there is still little experience in using remote sensing techniques and in working effectively with the gathered data for the assessment and monitoring of the effects of active or abandoned mines on the environment. This is vitally important in evaluating surface water quality and environmental damage through acid mine drainage using remote sensing methods (Paktunc, 1999; Sabins, 1999). It is evidenced that AMD cause changes to mineral content and composition of tailings and also the land use related to mining activities (Charou et al., 2010; Choe et al., 2008; Schaefer et al., 2007).

Various research findings on AMD and mineral classification (Kemper and Sommer, 2002; Ong et al., 2003; Riaza and Müller, 2009; Riaza et al., 2006; Swayze et al., 2000) and on eutrophic inland water classification (Jahnen and Grassl, 1992; Thiemann and Kaufmann, 2002) are available in scientific literature. An overview of AMD and its impacts on the environment is outlined by Azcue (1999) and Geller et al. (1998). However, the application of remote sensing to classify the impacts of sulfide (Anderson and Robbins, 1998) on water bodies inside the mines is still not complete.

Lignite has been the main source of energy for a long time in many countries all over the world. In regions such as Eastern and Central Germany, it is still the most important source for chemical industries. Only in 1988, more than 300 million tons of lignite was mined in these

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areas. Since 1990, 120 of approximately 500 pit lakes resulting from lignite mining in Eastern Germany (Nixdorf et al., 2005) have been filled to meet modern environmental standards. An overview of the water quality management in these pit lakes was given by Schultze et al. (2009).

Hyper-spectral airborne remote sensing has been used successfully for monitoring and hydrochemical classification of lignite mining lakes (Frauendorf, 2002; Gläßer et al., 2011). However, due to its high cost, this method has not yet been applied on a large scale. The first investigations by Jäcklin (Gläßer et al., 2000) indicate a great potential of Landsat TM data for effective monitoring of mining lakes and can be used to develop a regional scale monitoring system for residual mining lakes by taking advantage of the excellent database available to this study area. This study was conducted on several lakes of the Bitterfeld complex (see Section 3).

2. Current state of remote sensing for characterization of mining lakes

Recording hydrochemistry of inland waters remote sensing data were used in numerous studies (Bukata et al., 1995; Dekker, 1993; Domínguez Gómez et al., 2009; Gege, 2004; Heege and Fischer, 2004; Heege et al., 2005; Thiemann and Kaufmann, 2002; van Tol et al., 2003). However, the field of research in remote sensing studies on open cast mining lakes is not published as often. An assessment of mining lakes in classical limnological classifications is challenging due to the various transition stages these lakes pass during their development process.

Pietsch (1979) classified mining lakes according to their water chemistry. These phases are called initial-, transitional-, early- and age-stage. As a result, a classification of artificial lakes in former mining areas into four different phases, that are characteristic to open-cast mine waters, is achieved. On the other hand, Gläßer et al. (2000) reported that the four-stage system was extended to a five system scheme (Table 1). In this system, water quality of mining lakes was implemented by using pH-values and ion-balance as well as water quality as content of carbonates, hydro-carbonates, aluminum-/ hydro-carbonate, aluminum and iron-buffer areas (Geller et al., 1998). Dekker (1993) in turn recommended a semi-empirical and analytical method in order to improve the classification of open-cast mining lakes.

The use of a compact airborne spectrographic imager (*casi*) in the period from 1998 to 2000 improved qualitative and quantitative characterization of open cast mining lakes (Frauendorf, 2002; Frauendorf et al., 2001). Open cast mining lakes were systematically investigated for their optical properties (Boine and Gläßer, 2000) and derivation of water quality parameters from remote sensing methods were developed and applied. Absorption and backscattering properties were used as basis for the distinction of the mining lakes, which showed the most noticeable differences from each other. The developed algorithms demonstrated a feasible applicability to airborne hyperspectral scanner data and thus proved suitable for the surveillance and monitoring of mining lakes (Boine and Gläßer, 2000; Gläßer et al., 2000). Methods of a comprehensive field spectrometry and numerous water analyses in the laboratory were implemented to study the correlation between these two. Mining lakes were then analyzed with regard to their spectral signatures, they were examined, classified and assigned to the respective final limnological stage (Boine and Gläßer, 2000; Frauendorf, 2002; Olbert et al., 2001) as shown in Table 1.

The use of remotely sensed and acquired datasets will increase significantly over the next several years due to the increasing use of multi-sensor and hyperspectral approaches. However, the methods used up to this date are not sufficient. Additionally, the quantity of data that has to be stored will further increase in the future, so computational and data storage capability will be exhausted and the handling of the increased dimensionality of such spectral information will be difficult if not impossible.

3. The test site presented in this study

The test site, named Goitzsche, presented in this paper is shown in Fig. 1 and is primarily characterized by the availability of an extensive knowledge of the evolution of the lakes situated there, their chemical properties and the already existing hyperspectral algorithms. Hence, this case study can be used and be extended to monitor mining lakes on a regional scale for similar regions worldwide with remote sensing data from operating satellites.

The test site studied exemplary in this paper is located in the northern part of North-West Saxony, Bitterfeld complex (Fig. 1). The Bitterfeld complex consists of two parts: the Goitzsche complex (Mulde reservoir, Mühlbeck, Niemegk, Döbern and Rösa) and the Holzweiβig complex (containing 4 mining lakes: Holzweiβig East, Holzweiβig West, Lake Ludwig and Paupitzsch).

Lignite deposits in this area are originated from the Tertiary age, Upper Oligocene to Lower Miocene. Different lignite seams with thicknesses up to 15 m were excavated during the mining operations over the past years. Fig. 2 portrays a general stratigraphic profile of this area (Schreck and Gläßer, 1998); its development was described by Eissmann (2002a, 2002b).

Various successive marine transgressions led to the formation of silts and sands in this lignite mining area. The influence of forests and swamps led to the development of the marginal parts of the Tertiary basin in areas where freshwater inflow occurred. The remaining peat layers were covered by sand and silts from subsequent transgression. Thus, the Tertiary strata profile contains marine estuarine and fluviatile sediments, such as marine sands, silts and clays, continental sands and conglomerates, estuarine micaceous, carbonoceus silts and sands and lignite seams. In the Quaternary period, the masses of ice during the glaciations of the Pleistocene epoch induced most of the effects, such as glaciofluvial erosion and glacigenous foliation, on the lignite-bearing sequences (Schreck and Gläßer, 1998).

During the period of active mining in this area, the groundwater table descended by up to 70 m while the cover sediments above the lignite seams, including the upper aquifers, were removed. After the closure of the mines, groundwater level rose again and filled the cavities that were created by mining of lignite and overlying sediments. These pits were mostly flooded by surface water from nearby rivers. As a result of groundwater rise and flooding from surface waters, mining pits became residual lakes, whose water quality is variable and dependent on numerous parameters. These

Table 1
Different classifications for acidic lakes in open cast mine areas divided in optical groups.

Optical group	1	5	3	2	4
System Geller et al., 1998	Iron buffer	Aluminum/iron buffer	Aluminum/hyrdocarbonate buffer		Hyrdocarbonate buffer
System Pietsch, 1979	Initial stage	Early stage	Transition/age stage		Age stage
System Jäcklin (In: Gläßer et al., 2000)/Frauendorf, 2002	Iron stage	Aluminum stage	Transition stage I	Transition stage II	Carbonate stage

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