

An Analysis of Selected Water Parameters in Surface Coal Mines Using Multispectral Videography

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ABSTRACT: The spectral sensitivity of multispectral video data as a means to provide insight into selected water parameters in abandoned coal mine lakes affected by acid mine drainage is evaluated. Three-band multispectral video data — yellow-green (YG, 0.543 to 0.562 μm), red (R, 0.644 to 0.656 μm), and near infrared (IR, 0.815 to 0.827 μm) — were acquired over two small abandoned surface coal mine lakes in western Clay County, Indiana. Fourteen water samples collected from the water surface (0 to 4 cm) were analyzed to obtain data on iron ion (Fe^{++}) content and related pH measurements. The spectral response values (digital counts) of the video data for each band were correlated with iron ion content and pH to determine the ability of the individual video bands to detect varying degrees of acidity and iron ion concentration in the mine lakes. Among the three narrow bands of multispectral video data, the yellow-green band exhibited the highest correlation (r) with acidity (-0.69) and iron ion content (0.62).

INTRODUCTION

DURING THE LAST TWO DECADES several studies have used multispectral remote sensing data to identify or monitor various conditions of water quality (Weisblatt *et al.*, 1973; Deutsch and Estes, 1980; Lodwick and Harrington, 1985; Huang and Lulla, 1986; Lathrup and Lillesand, 1988), and their results have demonstrated the value of satellite data (i.e., MSS, TM, and SPOT) in water quality studies. Researchers in those studies related digital spectral data to various water characteristics in an attempt to identify spectral indices best suited to estimating certain water quality characteristics. The main foci of these studies were the identification of turbidity and chlorophyll/phytoplankton content. The results of the spectral analysis of satellite data have proved promising in several areas of water resource management.

References regarding water quality analysis of surface coal mines affected by acid mine drainage are uncommon. One of the major constraints on digital remote sensing for such studies lies in the spatial resolution of satellite data. In the case of waterbodies created by coal strip mining, most are small or at least are relatively narrow. The coarse resolution of satellite data is not sufficient to analyze specific water characteristics in most cases. In a recent study (Mausel *et al.*, 1990), multispectral video data, acquired with approximately 2.0 metre (m) ground resolution, were used to evaluate water turbidity in small water bodies in southwestern Indiana. This study identified multispectral video data as effective in the analysis of water Secchi depth characteristics and related phenomena.

Narrow band multispectral video data have been applied and shown to be effective in various applications, including soil moisture analysis, crop identification, and natural vegetation identification (Lulla *et al.*, 1987; Kramber *et al.*, 1988; Everitt *et al.*, 1989). The use of very narrow spectral bands with the spatial resolution associated with video data is often cost effective and provides the detailed information required for local scale analysis. Moreover, the spectral band configuration of video data can be easily and specifically designed to maximize information ex-

traction for a particular purpose. However, prior to any application, it is necessary to evaluate each of the narrow bands of video data for various Earth surface conditions to insure a more effective use of the data. This has been, in fact, the main focus of many studies using multispectral video data.

This study analyzed multispectral video imagery acquired over strip mine lakes to determine if selected narrow bands of video data are useful in identifying metal contamination and water acidity in a local mine area. Water acidity and metal contamination are major environmental concerns in a local mine environment. Low pH values and high metal ion counts support only limited water flora and will not support fish life, thereby destroying a significant part of the aquatic ecosystem. The Indiana Department of Natural Resources (IDNR) estimates that over 200 waterbodies in Indiana have water contaminated by acid mine drainage (S. Herbert, personal communication, 1989). Under provisions set forth by Public Law 95-87, water impacted by toxic mine drainage falls under Health, Safety and General Welfare guidelines. These guidelines prioritized effects according to their impact on a human population (Priority Levels One and Two) and environmental impacts (Priority Level Three). The IDNR has identified surface coal-mine contaminated water in all three categories (IDNR, 1989); however, the most widespread damages resulting from the effects of mining are environmental in nature (U.S. Dept. of Interior, 1977). Impaired water quality also carries financial burdens for water users, and developers often incur significant economic and financial cost. Financial losses are found in reduced recreational values, fish kills, and impaired water supplies for human and livestock consumption (IDNR, 1989); in addition, bank overflows can damage crops and trees.

STUDY AREA

The study site was a 3.5 hectare (ha) portion of a surface coal mine located in the western part of Clay County, Indiana (Figure 1). The site consists of three waterbodies formed as a result of surface mining. Of the three lakes within the area, only two were observed and sampled for the study. The third was not considered because it exhibited less significant contamination (pH near 7.0, low iron counts, and it supported aquatic life).

Mining in this area occurred prior to 1977 and thus preceded

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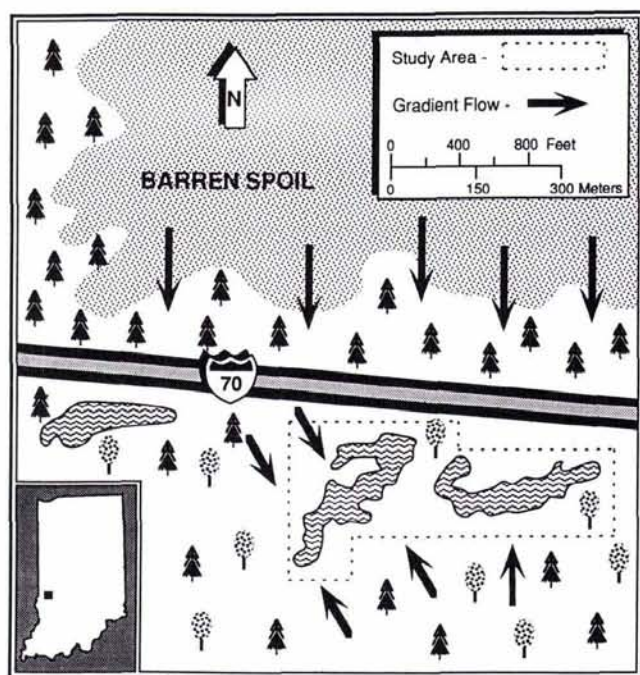


FIG. 1. Clay County, Indiana, study site.

the enactment of Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977, and hence no reclamation has occurred. The coal mined in the study area is designated as Coal III by Indiana Coal nomenclature as established by Ashley and others in 1899. Coal III is impure by three benches of iron disulfide which provide the raw material for acidity and ferrous ions. Acid mine drainage and high ferrous ion levels are the major environmental contaminants of water in the mined areas of Indiana (IDNR, 1989). The waterbodies in the study site were contaminated with heavy metals, and these metals lowered the quality of the water. Surface mining operations unearth iron disulfide (pyrite), which, when oxidized by naturally occurring atmospheric conditions, produces sulfuric acid and ferrous ions. Rainwater serves to make further soluble and transport these elements, which become part of the overland flow, as well as the groundwater, impacting the hydrologic regime of an area.

DATA AND METHODS

Video imagery of the study site was acquired on 18 May 1988 between 1200 and 1400 hours using equipment from the USDA's Remote Sensing Laboratory (Weslaco, Texas); a multispectral false color imaging system that provided color infrared composite imagery and its black-and-white image components (Nixon *et al.*, 1986). The system's two cameras [two visible sensitive (0.40 to 0.70 μm) and one visible infrared sensitive (0.40 to 1.50 μm)] were equipped with narrow band filters that obtained imagery in the yellow-green (0.543 to 0.552 μm) (Figure 2), red (0.644 to 0.656 μm), and near infrared (0.815 to 0.827 μm) spectral regions. The system was mounted vertically in the floor of an Aero Commander 6808 aircraft. The imagery was acquired at approximately 2400 m (8,000 ft) altitude with the focal length of the lenses set at 18 mm, providing a ground coverage of 1,730 m (5,680 ft) horizontally and/or a recorded image resolution of approximately 6 m (19.0 ft) per scan line horizontally. Each of the three bands of imagery was digitized at the USDA's Remote Sensing Laboratory in Weslaco, Texas using a MATROX MVP/AT board (512 by 512), formatted (BSQ). The three bands were registered for analysis utilizing ERDAS image processing software

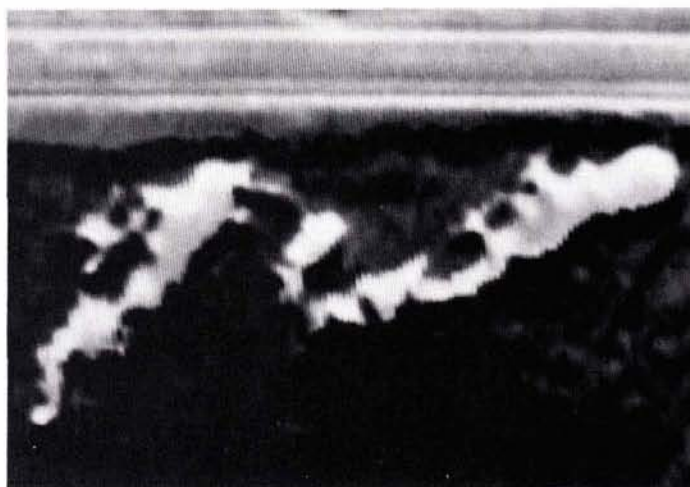


FIG. 2. Yellow-green video imagery of the study site.

at the Indiana State University Remote Sensing Laboratory (IS-URSL).

Water was sampled from 14 locations in the two lakes concurrent with video data collection in order to obtain and analyze chemical composition data. Fourteen samples were deemed representative based on the small size of the waterbodies and based on a sampling grid which was overlain on a map of the waterbodies. Data acquisition and water sampling occurred on a clear sunny day, with light surface winds (0 to 10 km/hour) providing a calm water surface. The last rain was light (less than 2.54 mm) and occurred ten days prior to data acquisition.

In an earlier study using these samples, it was determined that iron was the primary heavy metal constituent of these lakes, with manganese and zinc of much less importance (Lee and Repic, 1989). Thus, the iron ion content was considered the only heavy metal which significantly influenced the water quality. The iron ion content of the water samples was measured using the EPA 236.1 method (US EPA, 1983) in the laboratory, while related pH values were measured *in situ* during overflight through the use of a Hach digital test kit and checked with pH paper.

The digital video data were displayed on an ERDAS image processing system, and the location of each sample was found on the images (as accurately as possible on these small lakes, utilizing landmarks noted during sampling). It is unlikely that pixel locations of water sites on the ERDAS image match exactly with water sample collection sites in the fields, but they are very close. Thus, groups of pixels centered on a sample site were analyzed to minimize mislocation errors. Abrupt changes in the pH and metal ion concentrations in the lakes are unlikely; thus, the pixels selected to spectrally represent water samples are suitable for correlation analysis.

A 3 by 3 pixel spectral sample was developed for each water sample in each band, and the mean of the nine pixels was calculated. Atmospheric effects such as scattering and absorption were minimized as the data analyzed in this research were collected on a clear day from a low elevation (2400 m); thus, minor atmospheric effects at most were present. Therefore, the multispectral video data were not radiometrically corrected for atmospheric effects.

Simple Pearson coefficients of correlation developed between the spectral value and iron ion content and pH value to determine which band was more closely associated with the iron ion content and measured pH values, are presented in Table 1.

In order to further investigate the spectral sensitivity of video data with pH, the iron ion concentrations of the 14 water samples were clustered using minimum distance rules of the Cluster

TABLE 1. PEARSON COEFFICIENT OF CORRELATION BETWEEN VIDEO BANDS AND IRON CONTENT AND pH MEASUREMENTS.

Band	Iron Content	pH
YG	0.624*	-0.697*
R	0.264	-0.284
NIR	0.173	-0.426

*Significant at the 0.05 level.

procedure in the Statistical Analysis System (SAS) computer package (SAS, 1985). Five clusters were identified by the data and are presented in Table 2 along with related mean digital counts. Plots of the iron ion concentrations clusters were related to spectral values in each band, and an analysis of variance (ANOVA) was performed to determine whether those clusters were spectrally different in each video band. The null hypothesis was that spectral means of all iron ion concentration clusters were similar. F-ratio values are presented in Table 3. This procedure was used to confirm the results from the correlation analysis between the spectral video bands with pH and iron ion content. The pH measurements were not related to spectral values in this procedure, because the acidity was expected to generate the same result as that using iron ion content.

RESULTS

The highest correlations, significant at the 0.05 level, were associated with the yellow-green band (Table 1). The spectral video data in the yellow-green bands were positively correlated with iron ion concentration and negatively correlated with pH, possibly because increasing iron in solution is caused by increased acidity. Interestingly, the yellow-green band was identified to be uncorrelated with water Secchi depths in an earlier study using the same data, but different lakes. In a recent study (Mausel *et al.*, 1990), using data acquired at the same time as that used in this research, the multispectral video data used were related to Secchi depth measurement for silt-dominated water turbidity analysis. In this study, the yellow-green video band of video data showed a 0.004 correlation with Secchi depths, while the red band showed the greatest potential for Secchi depth analysis with a -0.834 correlation among the three individual bands.

The yellow-green band showed a 0.624 correlation with iron ion content and a -0.697 correlation with pH measurement. The higher correlations using yellow-green data are most likely attributable to increases in iron ion content turning the water color to yellow-orange, which makes the yellow-green band more sensitive to the increasing iron ion content than the other two bands. Field observation of the study lakes corroborated the deep yellow-orange color.

The highest correlation values in the yellow-green band can be attributed to the increased ability of this sensor to penetrate water surfaces using this band which was the best among the spectral ranges used in this study. However, it is not the thrust of this study to associate spectral values with penetration ability. More importantly is the hypothetical relationship between the energy and the yellow-green band and ferric iron ions. Exposure of pyritic materials to an oxidizing environment catalyzes a chemical reaction in which the ferric disulfide is altered initially to a ferrous state and to completion as ferric hydroxide ($\text{Fe}(\text{OH})_3$). Ferric hydroxide precipitates or flocculates form what is referred to as "yellow boy." The relationship between yellow-green energy and the yellowish color presented by the yellow boy floccs or precipitates may indicate the potential sensitivity for yellow-green energy to ferric iron contaminants.

Theoretically, the amount of radiance resulting from atmospheric scattering and absorption would be the greatest in the

TABLE 2. CLUSTERS OF IRON SAMPLES WITH ASSOCIATED pH AND SPECTRAL MEAN VALUES.

Cluster	Sample	Iron*	pH	YG	R	IR
1	1	25.0	6.72	146.8	148.0	28.3
	9	28.8	6.70	154.9	142.4	27.3
	13	36.2	6.12	162.0	146.6	84.2
2	3	140.0	6.32	184.4	160.7	59.4
	6	44.3	6.71	139.6	109.7	18.6
3	7	45.1	6.70	135.8	107.0	17.4
	8	50.0	6.71	136.8	134.9	26.4
	10	86.2	6.29	187.7	124.0	17.3
4	14	86.0	6.35	153.7	124.2	67.6
	11	86.6	6.22	182.6	108.8	12.8
	2	85.0	6.29	199.8	161.9	16.8
	4	90.4	6.30	156.4	128.9	31.3
	5	90.8	6.23	160.0	148.1	23.4
5	12	113.0	6.21	167.8	147.7	40.0

Note: Spectral video values given are the mean of nine (3 by 3) pixels.

*(mg/l)

TABLE 3. F-RATIO VALUES AND TEST RESULTS.

Band	F-Ratio Value	Test Result
YG	3.778	Reject Ho:
R	2.068	Accept Ho:
NIR	0.795	Accept Ho:

Ho: All the iron concentration clusters are spectrally the same.

yellow-green band, among the three individual bands used. Thus, slightly unequal variance caused by atmospheric effects is to be expected among the bands; however, this was not a significant factor in the analysis. Unlike the yellow-green band, the red and near infrared bands showed insignificant correlations with both iron and acidity. As seen in Table 2, the near infrared band shows a wide range of spectral values. This might be due to occasional slicks of green vegetation and pollen on the surface of the water. Such was the same upon field observation. Unlike turbidity studies by Weisblatt *et al.* (1973) and Mausel *et al.* (1990), the red band showed very low sensitivity to the iron and related acidity measurements.

Table 2 illustrates the grouping of the water samples into five clusters based upon iron ion content. These iron ion concentration clusters were plotted against spectral video values in each band and were not spectrally separable in all bands. The analysis of variance (ANOVA) test was performed to find out whether those clusters are significantly different in spectral values for each video band. The results of ANOVA F-Ratio testing (Table 3) revealed that the iron ion concentration clusters were deemed significantly different in their spectral values only in the yellow-green band. In all other bands, the null hypothesis, which states that "all the spectral means of all iron ion concentration clusters are the same," was accepted at the 0.05 level. This fact confirms the results from the correlation analysis.

CONCLUSIONS

The results reveal that the yellow-green video band data were most sensitive to iron ion content and pH of the water bodies in strip mine areas. Red and near infrared bands were not sensitive to iron content and pH in this case. These results were quite different from the silt dominated Secchi depth analysis by Mausel *et al.* (1990) where his research identified the yellow-green band as not being correlated in a similar setting. Water turbidity analysis using spectral digital data depends on the

ability of multispectral bands to penetrate into a waterbody. However, in this study, it was more likely that water color, induced by iron ions, was a more significant factor influencing spectral values. This suggests that each band of multispectral video data may have different potentials for water quality analysis depending upon the constituents of the water body.

This study also suggests that a yellow-green band of video data could be used to monitor degrees of iron contamination and resulting water acidity in coal strip mine drainage area. Additional research using yellow and yellow-orange bands needs to be conducted, because these wavelengths are even closer to the optical colors associated with the iron ion concentrations than is the yellow-green band. Further testing of additional narrow bands of video data is required to identify their potential in assessing water quality characteristics other than iron.

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International Education Program for Radarsat

Radarsat International Inc. (RSI) of Canada and the International Institute for Aerospace Survey and Earth Sciences (ITC) of The Netherlands have signed an agreement to jointly design and prepare an educational and training program on the principles, capabilities, and applications of RADARSAT I. This Canadian synthetic aperture radar (SAR) satellite is scheduled for launch in 1994/early 1995. RADARSAT I, representing the first commercial operational radar satellite, will provide users with 5 years of satellite SAR data and will be followed up by RADARSAT II and other commercial operational radar satellites.

The RSI-ITC international education and training program will consist of 4 components: 1) Preparation and design meetings; 2) Executive seminar series for senior decision makers; 3) Workshops on the "Introduction to RADARSAT"; 4) The RADARSAT applications workshop series.

Training Need

RSI and ITC share a common vision of the need for education and training for the new generation of radar satellites. RSI views this agreement as a means to integrate the excellent work coming out of Canadian universities and institutes into a broader international program designed to reach national and regional decision makers, scientists, and natural resources program directors/managers.

International Network

ITC will coordinate exchanges of information and meetings between RSI and ITC's sister institutes in developing countries and other international centers in ITC's worldwide network.

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