REMOTE SENSING FOR CHARACTERIZING AND MONITORING OF HAZARDOUS WASTE SITES- CASE STUDIES IN CANADA AND GERMANY

Vern Singhroy
Canada Centre for Remote Sensing, Canada
Fredrick Kuhn
BGR, Germany

Commission V11, Working Group 7

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ABSTRACT:

This paper presents case studies in Canada and Germany on the use of remote sensing techniques for the characterisation and monitoring of hazardous waste sites. Particular attention is placed the interpretation of air photographs, airborne multispectral (CASI) , thermal, and TM data. The selection of the specific technique is based on the particular environmental condition of the site. The task is to evaluate and minimize the environmental damage. In the case of site characterisation, the role of remote sensing is to provide geological, hydrogeological, land use and land cover information.

The Sudbury mining district in Canada is home of one of the world largest metal smelting complexes and is well known as a polluted region. Mining and processing of nickel and copper has started 100 years ago. In this area multi date TM were used to characterize the extent of vegetation damage and monitor vegetation successes in the region. Our analysis have shown that over a 11 year period (1984-95), the vegetation regeneration has increased by 50%, and areas covered by mine tailings were reduced by 40%. Airborne multispectral images (CASI) were used to monitor revegetation success to rehabilitate the areas of mine and mill waste..

Germany is characterised by intensive land uses. Very short distances exist between waste sites, settlements, farmlands and waterworks. Air photographs, airborne multispectral and thermal images as well as have provided the following information:

- structures of uncovered deposits and the characteristic of the waste,
- sites with high hazardous potential,
- location of abandoned and covered waste sites
- characteristic of the soils and rocks at the basement of the waste sites,
- drainage systems and accumulation of pollution's outside of the waste sites.

These case studies selected from different environments will provide the guidelines on the uses of remote sensing for the assessment and monitoring hazardous waste sites.

1. INTRODUCTION

The deleterious effect of past hazardous waste is an international problem. In Canada and the United States alone there are over 100,000 abandon mine sites..Recent research have shown that multispectral remote sensing techniques can detect the vegetation damage caused by mine tailings, and can monitor the revegetation success at rehabilation sites.

In Germany, the land has been used very intensively for hundreds of years. Populated, industrial, and recreation areas, as well as water resources are close to land fills and mining areas. Detailed mapping scales at 1:1000 to 1:2000 are required. One of the main tasks for land fill monitoring is to investigate the volume of the waste, its impacts on surrounding areas, and to evaluate the property of the land fill basement. Old waste sites sometimes requires the existence of natural or artificial basements which can protect against waste drainage. These older land fills which are in direct contact with the ground water table are more in need of historic images as well as modern remote sensing data.

These case studies demonstrate how remote sensing can contribute in detecting and evaluating environmental risks at densely populated areas. The main focus is to characterize land fills and mine waste sites. Examples were selected from projects carried out within the last five years in Germany (Kuhn and Horig, 1995) and in Canada (Singhroy 1995).

This paper deals with several remote sensing techniques for characterizing and monitoring hazardous waste sites. Therefore, a brief review of some common multispectral techniques for detecting vegetation damage related to hazardous waste is given.

Many studies have shown that vegetation that has been geochemical stressed, (sometimes from acid mine drainage) will respond with changes in spectral reflectance (Gates et al.,1965, Collins, 1978, Horler et al., 1980, Collins et al 1993, Singhroy et al 1986). These changes have been observed at the green reflectance peak near 0.57 nm, the chlorophyll absorption maximum near 0.68 nm, and in the reflectance of the infrared reflectance shoulder and plateau regions between 0.75 and 1.1mm. Stress plants can result in chlorosis (chlorophyll loss). This phenomenon has been documented in reflectance spectra as the "red-edge shift", a change in the wavelength position of the inflection point that occurs between 0.68 and 0.75 nm in green vegetation spectra. Stress-induced shifts in the red-edge have been reported both toward longer (red) and shorter (blue) wavelengths, and have been attributed to changes in chlorophyll concentration and other plant parameters including canopy architecture and phenolgy etc. (Collins, 1998, Singhroy et al 1989, Horler et al, 1983, Rock, 1988, Ustin et al 1994, Curtiss et al 1989).The observation and measurement of the red-edge shift is difficult, requiring very high spectral resolution. Differences in wavelength position between stressed and healthy vegetation range from 0 (no shift) to 10 nm, but generally are less than 5 nm. (Singhroy et al 1986). This requires very high resolution field and aircraft spectrometers.

On the other hand, the chlorophyll concentration is a well defined parameter that has a direct effect on reflectance spectra. The absorption band analysis techniques developed for the analysis of minerals spectra can be used for vegetation. These methods have been in use for several years for mineralogical analysis. (Kruse et al,1990, and others). Singhroy and Kruse 1991 reported on the results of hyperspectral and narrow band multispectral images to characterize vegetation damage associated with mine tailings. The image processing techniques used the changes in spectral response of vegetation in the chlorophyll absorption bands at 680nm.

Several remote sensing case studies on mine tailings have been reported in Canada. The sensors used include airborne and spaceborne multispectral images and aerial video. Graham et al. (1994) used principal component analysis techniques on Landsat TM images to monitor vegetation changes on large areas affected by iron ore mining operations at Noranda, Quebec. Mussokowski (1983) used classification techniques of multidate Landsat TM data to monitor vegetation change over a ten year period in the Sudbury. Similar techniques were also used by Hornsby et al. 1989 at the placer gold mining areas in the Yukon. Digitize air photographs, integrated with topographic and drainage data were used to characterize gold mining areas in Timmins, Ontario (Mussokowski et al. 1993). Airborne multispectral techniques are the most effective to detect and monitor vegetation damage at mine sites, and have been used successfully by (Singhroy and Kruse, 1991, King, 1993, and Singhroy 1992).

2. DISCUSSION

2.1 Sudbury Case Study - Environmental Restoration.

The Sudbury mining district in Canada is one of the world largest metal smelting complexes and is well known as a polluted region, where the landscape has been devastated. Mining and processing of nickel and copper has started 100 years ago. Soil and vegetation were lost from tens of thousand of hectares of land surrounding the smelters. Lakes in the region were acidified and contaminated with metals. The damaged area surrounding Sudbury is of sufficient size that TM imagery provide a convenient means of monitoring changes in the vegetation. In this area multi-date TM were used to characterize the extent of vegetation damage and monitor vegetation successes in the region. A June 1984 and 1995 Landsat images,(Bands 3,4,5) were enhanced and classified to assess environmental change over the last 11 years. The results have shown (Figures 1(1984) and Figire 2 (1995)) that the areas covered by mine tailings have been reduced by 40% and vegetation growth has increased by 50%. This environmental restoration as shown from the analysis of multi-date Landsat analysis is the result of a well- integrated multifaceted approach to the development of environmental control technologies and strategies. As an example of one of the many strategies, Inco Limited now retains 90% of the sulphur in the mined ore, which is the reversed of 1960s, when 90% of the ore 's sulphur was emitted to the atmosphere as sulphur dioxide.(Gunn 1995)

Airborne multispectral images (CASI) were used to monitor revegetation success at Inco's Copper Cliff tailings area. The tailings area is the largest is the largest repository of reactive tailings in Canada. It covers approximately 5500 acres and contain more than 10% of all tailings in Canada. Tailings have been deposited in the basin since the 1930's, and future deposition has been designed for more than 30 years. Results have shown that the enhanced CASI images provided the spatial and spectral details to assess revegetation success at sites under rehabilation

Airborne SAR images were used to characterise the surface roughness and local fractures of the large tailing areas so as to prevent acid mind drainage.

2.2 Waste drainage at land fill basements.

One of the most important tasks for environmental geological investigations of land fill areas is the evaluation of their basement properties. The capability to prevent waste drainage from migrating into the soil and the ground water table is one of the main objectives for geological investigations at land fill areas. In every case the natural basement of a land fill is covered by waste.

Geophysical methods can penetrate the waste and provide information on structural features, soil properties or distances to the ground water table. A combination of geophysics and the evaluation of historic air photos can contribute to describing rock properties at the land fill basement.

Despite modern in remote sensing technologies, historic air photography is an important tool to get high resolution data of the former land surface that is now covered by the land fill. In this case a 1945 air photograph provides a detailed view at the topography of the land fill basement. The photo (shown in oral presentation) characterizes the property of the natural land fill basement. The main rock unit of the basement, in this case, it is a highly rugged limestone. It is covered by clay and loamy sediments (thickness: 1 to 3 meters). Normally, that rock would protect the underground against the inflow of waste drainage coming from the overlaying land fill. In this case, natural protecting capabilities of the topsoil were disturbed by creating the building pit. Contaminated water can penetrate the rugged limestone without any obstacles and migrate outside by using the natural ground water flow.

This example shows that historic air photos âre effective low cost method to assess landfill basements.

2.3 Hazardous materials dumped within mine and mill tailings

Thermal infrared images can detect materials whose decomposition produces relatively high temperatures compared to their surroundings. The site is a mine and mill tailings (shown in presentation). One of the main environmental problems of the site is being caused by dumped pyrites and carbon shale. Oxidizing pyrite by produces sulfur. Contact of the sulfur with rain water produces acid drainage. The acid drainage has contaminated the ground water at the site. Therefore, the knowledge about the location of the oxidizing pyrites is needed to take steps against that process. The oxidation of the pyrites causes the inflammation of the carbon shales which produces an increase in temperature. The temperatures are detectable at the surface, even if the oxidizing pyrites are covered by thick layers of other material. In this case, thermal remote sensing is a very prospective tool for detecting the locations of the pyrites. Thermal anomalies (shown in oral presentation) indicate the locations of a pyrite bearing tailings. The average surface temperature outside the area is about 5°C. The areas characterized by radiation temperatures >25° correlate with accumulations of pyrites and carbon shales. Temperatures up to 36,1° could be measured in some areas.

This example shows that thermal remote sensing has assisted in the detection of serious risks for the soil and the groundwater. The data have helped to take steps against the sources of acid generation within the mine and mill tailings.

2.4 Waste drainage with the natural ground water flux

Large areas in the northern part of Germany are characterized by glacial sediments and shallow groundwater table. Since the beginning of the century, hundreds of land fills were located in that area, around the large towns and settlements. Many sites are characterized by waste that was dumped while eliminating the destruction of the World Wars I and II. These sites contained dangerous materials in decaying containers which contaminate the groundwater.
A land fill near Berlin is shown on the CIR-air photograph (oral presentation). The site is characterized by a shallow ground water table. The lower waste materials are in direct contact with the ground water. Colors, varying from dark black to blue characterize the surfaces of the water-filled quarries. According to field information, the blue color corresponds with an increase in algae populations. It is caused by nutrients that are provided by the natural ground water flux. The CIR-air photo gives the following information: First, there is an ongoing transportation of dissolved waste particles to the outer areas. Second, the direction of the transportation is northeast to southwest according to the direction of the natural ground water flux Third, the site southeast of the land fill has to be investigated by hydrochemical prospecting for accumulations of contaminants.

2.5. Waste drainage migration

This example shows a CIR-air photograph (July 3, 1993) and vegetation index image derived from CASI image (June 26, 1993) of the same site (colour figures in oral presentation). The compilation of the vegetation index $VI=(IR-R)\div(IR+R)$ the CASI bands R:663,9-680,5 nm and IR: 737,7-752,5 nm have been used. The light area on the CIR-air photograph indicates losses in the growth of grain. This is caused by a sandy top soil with a poor capability of accumulating moisture.

Different stages of vegetation coverage and vegetation types in the area investigated are indicated by different values of the vegetation index. The sandy area (VI: 0.2 to 0.4) were mapped clearly, and is important for the prediction of potential risks, since this site is characterized by an extremely shallow ground water level. Therefore, the area outlined by sandy sediments can be regarded as a „window“ between the site's surface and the ground water table. Waste drainage coming from the nearby land fill would be able to penetrate the sediments directly, within a very short time and without a minimum of filtration. Serious problems for the ground water will arise, if waste drainage can flow through that „window“.

2.6 Contamination of the soil and ground water.

The north German flat country are characterized by shallow ground water levels. In these areas, the roots of trees are in a direct contact with the ground water. Thus the quality of the ground water has affected the spectral reflectance of the trees. This technique is being used to detect contamination of the soil and the ground water. This example shows a map of damages on single trees, tree-rows and groups of trees having compiled by evaluating treetops on CIR-air photographs. Three types of trees were selected for evaluation: willows, poplars and alders. During initial field checks, four levels of the treetop shape have been determined and correlated with their appearance on the CIR-air photographs: First, trees without visible damages (green), Second, trees with low level damages (yellow), Third, trees with higher level damages (brown) and finally, extremely damaged trees.
CASI airborne imaging spectrometer data was flown about one week before CIR-air photography. On the CASI image, we recognize the transition from lowly damaged trees (yellow) to heavily damaged trees (red). However, without support of information provided by CIR-air photography, it would have been impossible to decide between the colour change caused by the contaminants and the plant reflectance.

2.7 Environmental impacts on military training areas

In Germany today, properties once used for military purposes are being released for civilian uses. Contamination and other environmental damage from decades of military use is extensive. Many kinds of environmental damage are present. Apart from the risks emanating from unexploded or buried munitions, the most common problems include contamination of the soil and groundwater by petroleum products and ammunition residues, impairment of the vegetation, destruction of the natural soil horizons, and erosion damage.
Because military training areas are large and access to parts of them is difficult, it is generally impossible to collect sufficient information on soil and groundwater pollution solely by using conventional ground-based methods of mapping. A reasonable solution to the problem is found by combining traditional geological and geochemical techniques with remote sensing. For an initial evaluation, remote sensing data provides information about the location and extent of areas in which soil pollution may be suspected. On the basis of this data, drilling, geochemical, hydrogeological and other investigations can then be carried out with better success and at lower cost.

Typical surface pattern of a military training area are shown by the large-scale aerial photograph (oral pres). Total destruction of the topsoil by the impact of numerous vehicles facilitates changes in the topography by erosion. As has been investigated by spectroradiometric measurements, the darker color of the soil along the main routes is caused by oil, possibly lubricants from armored vehicle tracks, oil from leaky gaskets or exhaust gases. The outlines of a destroyed underground facility from the WW-II period and several recent detonation craters can be seen in the center of the photograph. The entire area shows traces of excavations (field positions, shelters, underground pipelines and cables, etc.). All excavations are suspect: Hazardous substances or live ammunition may have been left behind or disposed of and may have contaminated the subsoil.
The digital processed Deadalus scanner image covers the central area of the black & white air photograph. It has been processed using the Deadalus channels 3, 5 and 7. This image shows details of the contaminated areas.. The craters in the center of the image are the result of the destruction of old ammunitions. The craters are surrounded by suspiciously colored areas. In these areas, explosives residues (TNT and its decomposition products dinitrotoluene and aminodinitrotoluene) in concentrations of up to 88.8 mg/kg have been found.
Direct recognition of specific substances in the top soil is difficult from the wide spectral bands of the Daedalus ATM scanners. However ,preliminary results of field spectrometer measurements in the same area have shown that oil contaminated soils could be detected directly using airborne imaging scanners .

3.SUMMARY

This paper briefly reviews the current status of spectral characterization of areas of mine tailings and provides several examples on the use of air photos, airborne multispectral techniques, thermal images and multi-date TM to characterize and monitor hazardous waste sites..

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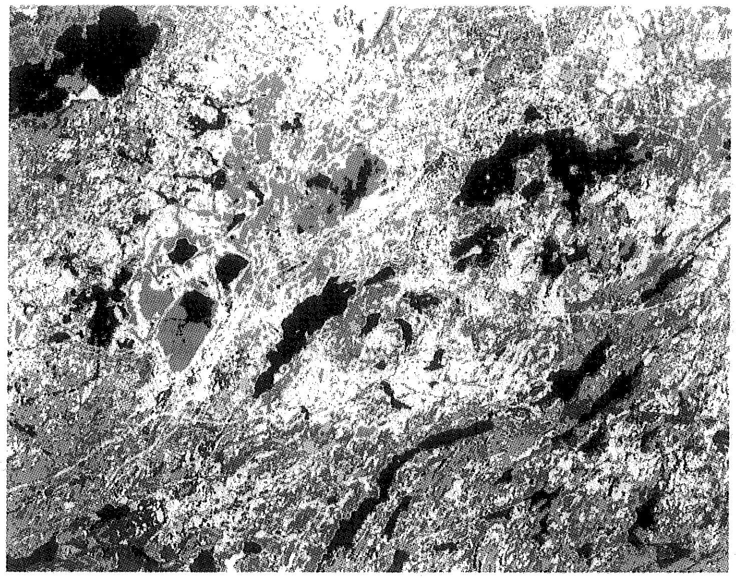
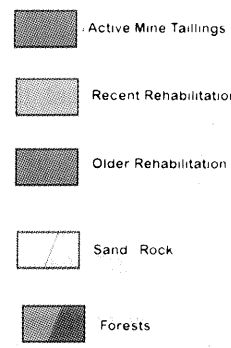
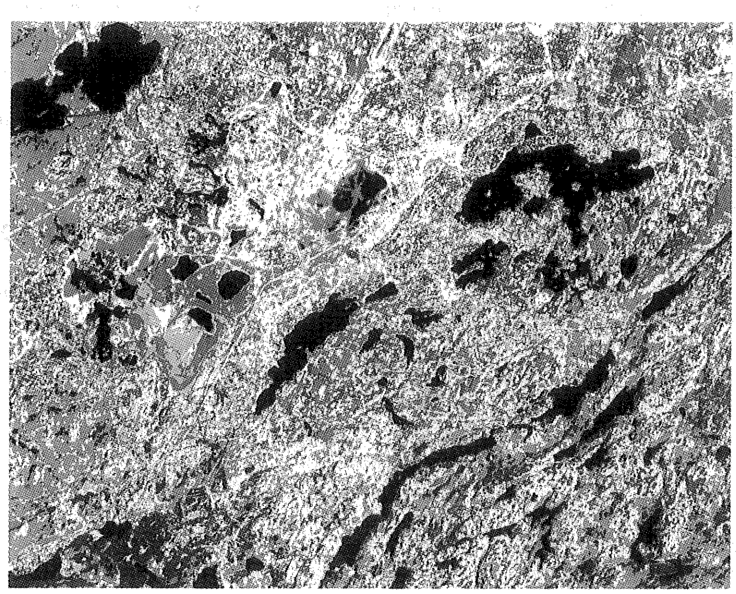


June 1984 - Unsupervised classification





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