IDENTIFICATION AND CHARACTERIZATION OF MINING WASTE USING LANDSAT THEMATIC MAPPER IMAGERY, CHEROKEE COUNTY, KANSAS[1]

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Abstract. Mining wastes and tailings are present throughout much of the world and United States including the Tri-State lead and zinc mining district in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma. These wastes and tailings are often associated with heavy metals, acid mine drainage, and other physical hazards. Many tools have been utilized and proposed for the rapid inventory and characterization of these wastes including the use of Landsat Thematic Mapper (TM) images. A Landsat TM image of the Cherokee County, Kansas portion of the Tri-State mining district was evaluated in an attempt to inventory mining waste and tailings in the county, and characterize the gross mineralogy of these wastes. False color TM composites were used to perform supervised and unsupervised landcover classifications of Cherokee County to identify the locations of mining waste and tailings. In addition, several TM band combinations (mineral indices) were used to characterize the mineralogy of these wastes. The accuracy of the classifications in identifying mining wastes from other land types was less than 60 percent. However, false color composites of Landsat TM bands were a useful tool in identifying these wastes, and determining their gross mineralogy.

Additional Key Words: Tri-State District, Remote Sensing, Landsat TM

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Introduction

Problem

Abandoned mines and mine wastes are present throughout the country and world. Peters and Hauff (2000) estimate that there are between 100,000 to 500,000 abandoned mine land sites throughout the United States. These sites are often associated with toxic substances, acidic mine drainage, and may also present physical hazards such as subsidence and tailings dam failures.

Cherokee County in the southeastern part of Kansas is part of the Tri-State mining district (Fig. 1). Lead and zinc ores were mined in this area from about 1848 to 1968 (Brockie et al. 1968; Ragan 1996). The mining and smelting of these ores in the Tri-State area has left a legacy ranging from mine tailings dotting the landscape, to metal-contaminated soils, sediments, surface water and ground water (Dahlinger 1988). Over three billion metric tons of chat (mine tailings) were produced in the Tri-State district according to Dahlinger (1988). These tailings contain elevated levels of lead, cadmium, zinc, and other metals, and vary in size from coarse boulder-sized waste rock referred to as "bullrock," pea-sized tailings referred to as "chat," and finer sized tailings (U.S. EPA 1986, 2000).

Recognition of these abandoned mine lands and characterization of the associated wastes and/or tailings is often problematic due to their widespread geographical distribution as well as the fact that mine tailings/waste may have been moved from the original mine site for processing, smelting and disposal. Several methods have been proposed for the rapid inventorying and characterization of these wastes, including the use of remote sensing techniques such as aerial photographs, hand-held spectrometers, AVIRIS images, and satellite imagery such as SPOT and Landsat MS and TM data (Fenstermaker and Miller 1994, Peters et al. 1996, Peters and Hauff 2000, Singhroy 2000, Swayze *et al.* 2000). This paper addresses the use of Landsat TM data for the inventorying and characterization of metal mining wastes in the Cherokee County, Kansas portion of the Tri-State mining district (Fig. 1). This provides the potential of identifying wastes and pinpointing their locations for further analysis, and conducting a gross characterization of their mineralogy.

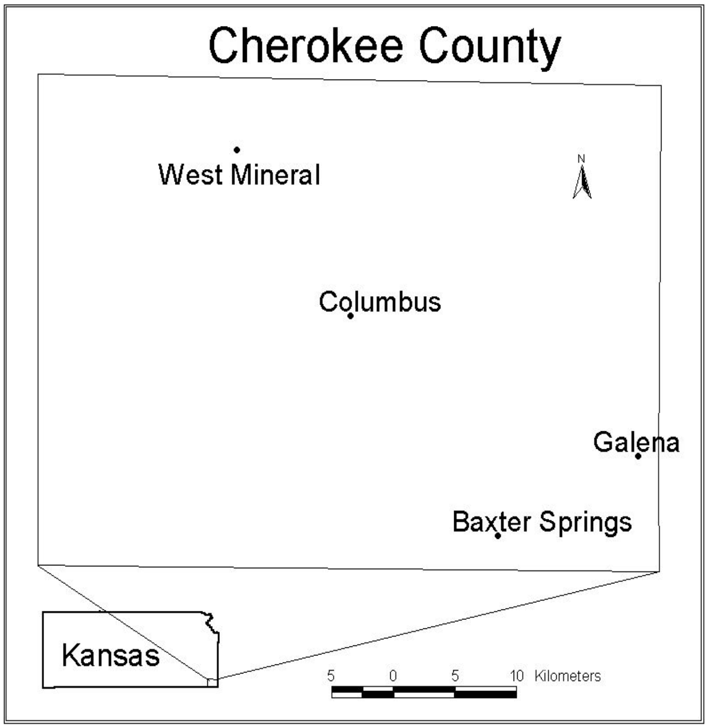

Figure 1. Location map of Cherokee County, Kansas showing major towns.

Hypotheses

The following hypotheses were tested regarding the use of Landsat TM imagery for Cherokee County:

- Metal mining waste/tailings in the county are recognizable in a Landsat TM image, and should have enough spectral differences from the surrounding land cover types to allow for mapping their distribution using supervised and unsupervised classification techniques.
- The broad mineralogical characteristics of the identified metal mine wastes/tailings can be determined from the Landsat TM imagery.
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Previous Studies

Several studies have addressed the use of remote sensing to inventory and characterize mining waste. Kenny and McCauley (1982) used aerial photographs to conduct an inventory of abandoned coal mine lands in the north and central portions of Cherokee County, Kansas. They noted that much of the abandoned lands supported dense vegetation growth, and were able to identify waste and potential acid mine drainage locations. Peplies et al. (1982) also used aerial photos for the identification of abandoned mine lands and waste in the Tug Fork Basin in West Virginia. Peters et al. (1996) and Peters and Hauff (2000) investigated the use of Landsat TM imagery to inventory and characterize mining wastes/tailings in the Cripple Creek gold mining district of Colorado. They found that Landsat images allowed for the inventorying of waste locations, and furthermore allowed for the gross identification of mine waste mineralogies. Peters et al. (1996) and Peters and Hauff (2000) also used AVIRIS multispectral images and handheld spectrometers to further characterize the mineralogy of mining waste. Singhroy (2000) used Landsat TM images to monitor the effects of nickel and copper mining and smelting in the Sudbury, Canada area using unsupervised land cover classification to map changes in the amount of active mine tailings and vegetation in reclaimed areas. Finally, Watson and Knepper (1994) give a summary of the use of airborne remote sensing to address geology and environmental monitoring issues.

Study Area

Cherokee County lies mostly in the Cherokee lowlands physiographic region, with the extreme southeast corner in the Ozark Plateau physiographic region (Buchanan and McCauley 1987). Elevation ranges from approximately 300 m to 228 m, and the predominant land use in the area is agricultural with some intermixed forested land (Petersen et al. 1998). Precipitation ranges from 101 to 114 cm/year with mean annual January temperatures between -4 and 4° C, and mean annual temperatures during August between 27 and 32° C (Spruill 1987). Major towns in the county include Baxter Springs and Galena. The Cherokee superfund site is also located in Cherokee County, and includes the town of Galena (U.S. EPA 1999). This superfund site was listed by EPA in 1983, and has been impacted by acid mine drainage, mining, milling, and smelting wastes and contaminated groundwater, all of which have elevated levels of cadmium, lead, and zinc (U.S. EPA 1999).

The Mississippian Boone formation consists of interbedded limestones and is the main host for the lead and zinc ore bodies in the Tri-State district with some ore deposits also found in the younger Pennsylvanian age rocks in the eastern Kansas part of the district (Ragan 1996). Secondary hydrothermal deposits rich in lead and zinc sulfides such as sphalerite (ZnS) and galena (PbS), make up the primary ores of the district. The ore deposits are known as Mississippi Valley-type deposits because they are similar to other carbonate hosted ore bodies in the Midwest (Ragan 1996; Coveney et al. 2000). The mineralization events are likely the result of metal-rich hydrothermal waters which flowed through the limestone bedrock system (Ragan 1996).

Methods

Geometric and Radiometric Correction

A Landsat 5 Thematic Mapper image (Path 26 and Row 34, acquired June 27, 1992) was utilized to identify metal mine wastes and tailings associated with the Cherokee County, Kansas portion of the Tri-State mining district. The entire image was subset to remove band 6 (thermal infrared) due to its coarse resolution. The image was then geometrically rectified to UTM Zone 15 WGS 84 coordinates using a first order polynomial equation. This equation was produced from 11 ground control points acquired from 7.5 minute U.S. Geological Survey topographic maps of the area and yielded a root mean square error of less than 1 pixel. Nearest neighbor resampling was used to retain the original pixel DN values and limit the distortion of spectral features (Jensen 1996). The image was then radiometrically and atmospherically corrected using an Excel spread sheet and ERDAS model to convert DN values to reflectance values (Skirvin 2000). The Skirvin (2000) spreadsheet and ERDAS model is based on the Chavez (1996) COST model and reflectance values provided by Markham and Barker (1992). Geometric rectification was utilized in order to have control of actual waste locations, while radiometric and atmospheric correction was performed because of recommendations by Song *et al.* (2001) regarding the use of band ratio indexes. Following image correction, bands 7-4-2 were coded red, green, and blue, respectively, to promote the visualization of geologic features and mineral reflectance (Peters and Hauff 2000). A standard 4-3-2 band false color composite image was also produced.

Classification

The image was classified into land cover types using both supervised and unsupervised classification methods. There were two land cover types chosen: 1) metal mine waste/tailings and 2) other land cover. Supervised classification was performed by first producing reflectance signatures by using known waste areas on the image for the mine waste classification training, and nonmine waste areas for the other signature training. The nearest neighbor method was then used to classify the image (Jensen 1996). This method was chosen due to the skewed nature of some of the band reflectance histograms. Unsupervised classification was performed using ISODATA cluster allocation (see Jensen 1996) to cluster the reflectance values initially into 30 clusters, which were then placed into the two classes. Unclassifiable clusters were masked, and additional unsupervised classification (cluster busting) was used in an attempt to provide further resolution in the reflectance areas similar to the mine waste signatures.

The overall accuracies of the classifications were assessed using stratified random sampling (n = 50 per class). The accuracies of the classifications were checked using a one meter x one meter resolution orthophoto of Cherokee County (1991 acquisition), and 7.5 minute U.S. Geological Survey topographic maps (showing the location of some tailings) to produce an error matrix table (Jensen 1996). Finally, histogram equalization was performed on the originally corrected image, and supervised nearest neighbor classification used on this equalized image in an attempt to further refine the mine waste/tailings locations.

The classified ERDAS images were then pulled into ArcView (version 3.2) and grid files formed. These grid files were then converted to shape files to separate the mine waste/tailings classification from the other land cover classification.

Mineralization and Weathering Characterization

Combinations of band ratios were utilized in an attempt to characterize the mineralogy of the area and waste deposits following the methods used by Peters and Hauff (2000). Band ratios used included 3/4-3/1-5/7 to detect iron oxides, 3/1-5/4-5/7 to detect iron oxides and ferrous minerals, 7/4-1/5-1/7 to separate clay wastes from non clay wastes, and 5/7-3/1-4/3 for hydrothermal deposits.

Results

Landsat Image Bands 7-4-2

The geometrically and radiometrically corrected image is shown with bands 7-4-2 color coded red, green, and blue (Fig. 2). Note that some of the mine waste piles have been outlined in yellow on the figure. The wastes have a purple to blue coloration in the image, and are easily detectable based on their color and sprawling form. However, there are many agricultural fields (crop land) which have similar colors to the mine wastes, but are distinguishable due to the angular geometry of their borders. Since this band combination helps to distinguish geology and soil types, the vegetation cover is probably low enough in these crop areas to allow for reflectance from the soil and/or bedrock to be viewed. Some of the coal strip mine areas are easily seen in the upper left portion of the figure as marked. The many black colored lines or stripes in the strip mine area are water bodies in the reclaimed strip mines, with vegetation showing up in green.

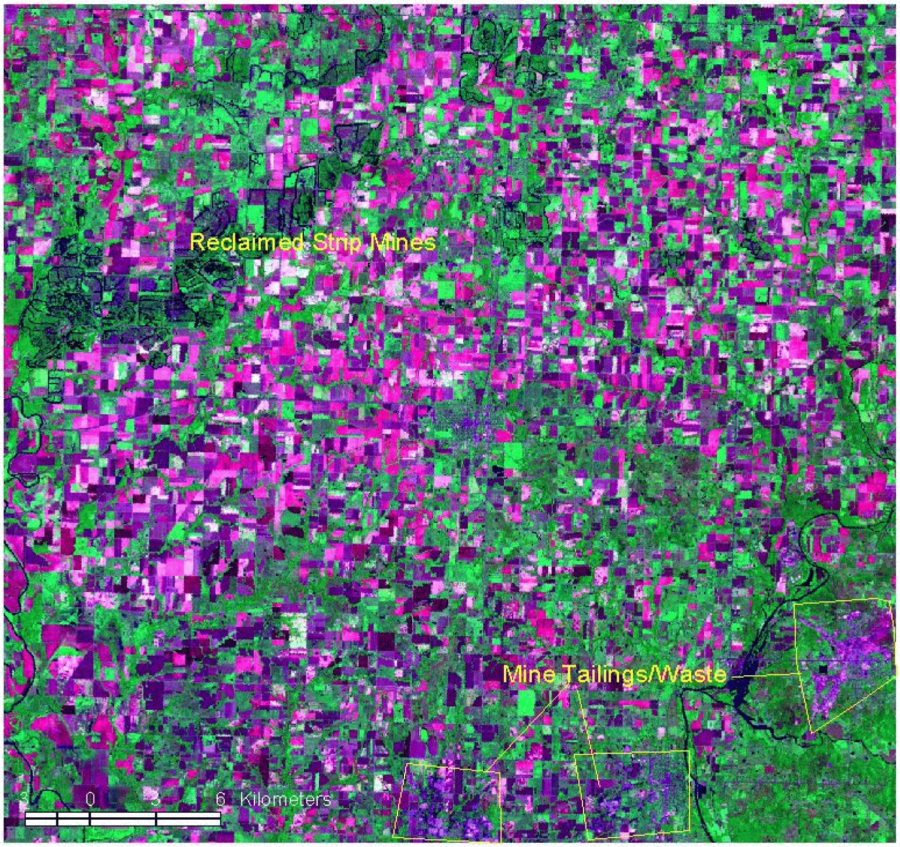

Figure 2. Landsat TM image of Cherokee County, Kansas (June 27, 1992). Bands 7-4-2 coded red, green and blue. Note the outlined purple colored metal mine waste areas in the lower right of image, and the coal strip mine area in the upper right indicated by green with black colored water bodies.

Classified Images

The classified waste areas appear as red and are found throughout the image (Fig. 3). An evaluation of the error matrix and kappa statistics (Table 1) shows that the unsupervised classification signature is very good at identifying wastes, but also includes many nonwaste cover types in the classification. The overall classification accuracy is about 58 percent, with 83 percent for producer accuracy (Type I error) for mine waste/tailings recognition. User accuracy is only 20 percent for the recognition of wastes (Type II error). The overall kappa statistic is 16 percent, and much lower than the overall accuracy. Further cluster busting may have helped to increase the accuracy of this classification. Also, ground truthing to determine if the substrate is actually mine waste or not, could also probably change the accuracy values.

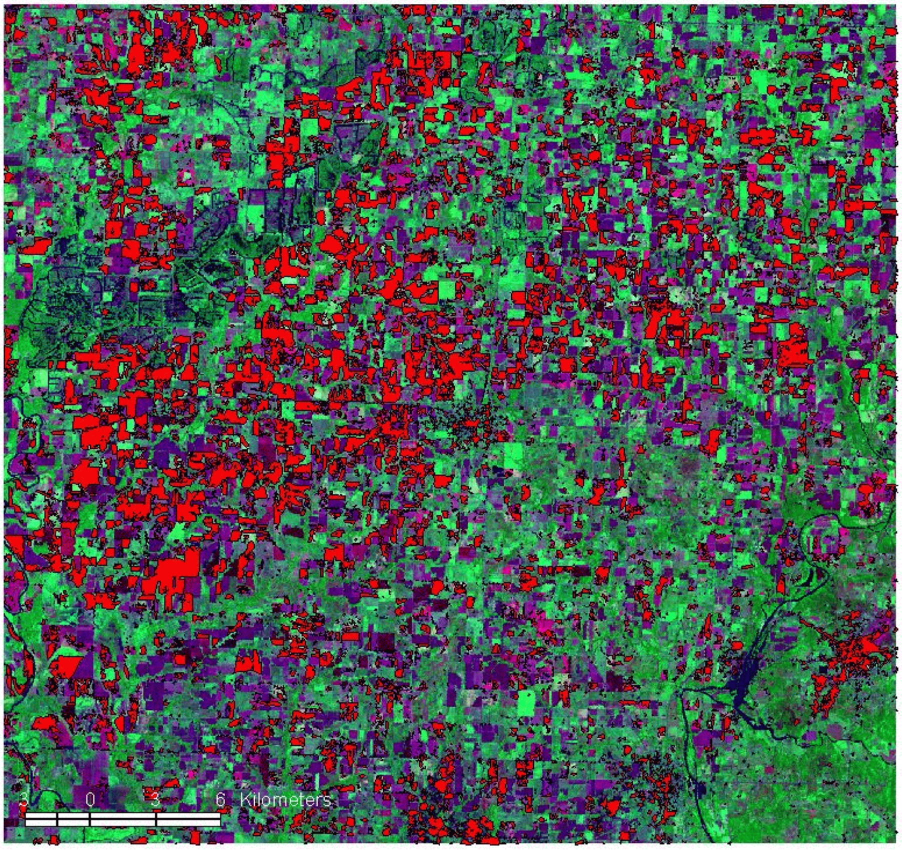

Figure 3. Landsat TM image showing unsupervised mine waste/tailings classification land cover in red for Cherokee County, Kansas (June 27, 1992). Bands 7-4-2 color coded red, green, and blue.

The supervised classification results for metal mine waste/tailings recognition are shown as yellow (Fig. 4). The overall accuracy was 57 percent, with the producer accuracy for the recognition of wastes at 89 percent (Table 2). User accuracy for the recognition of mining waste versus the other classification was 16 percent. The kappa score was 14 percent. The classification had a high percentage of waste recognition, but lumped many of the "other land cover" category into the waste class. The supervised classification did not recognize the full extent of wastes (Fig. 4).

Table 1. Error matrix for assessing accuracy of unsupervised classification.

	Mine waste/tailings	Other land cover	Row totals
Mine waste/tailings	10	40	50
Other land cover	2	48	50
Column totals	12	88	100

Overall accuracy = 58%	Users Mine waste/tailings accuracy = 20%
Mine waste/tailings producer accuracy = 83.3%	Users Other land cover accuracy = 96%
Other producer accuracy = 54 %	kappa (k_{hat}) = 16%

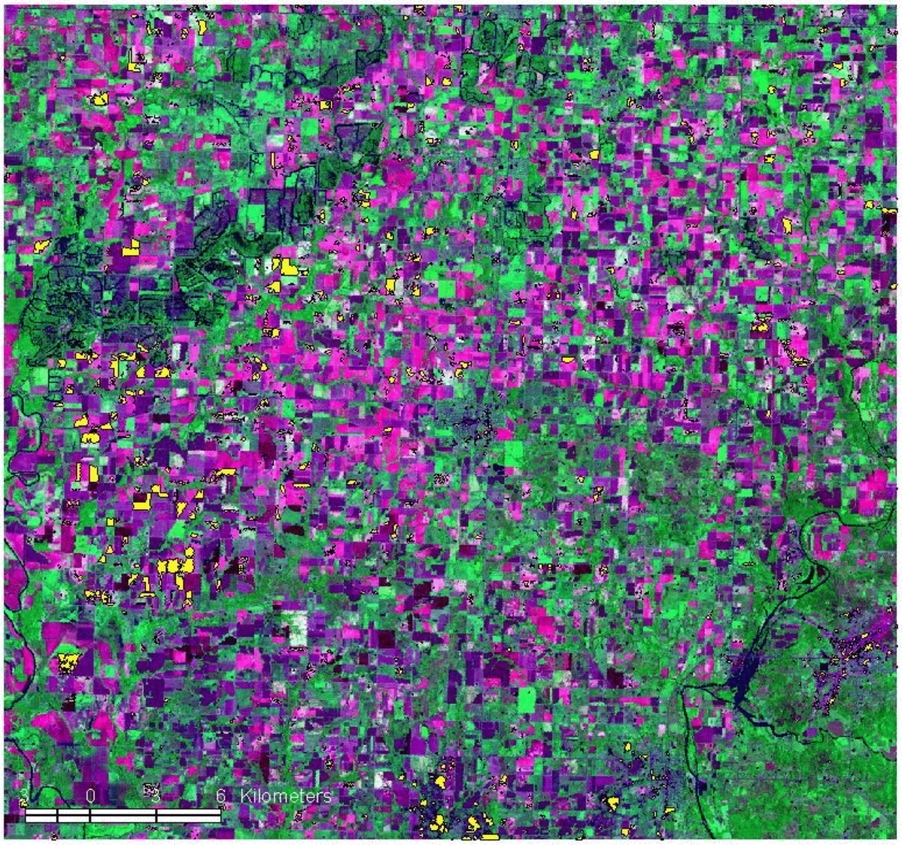

Figure 4. Supervised classification showing mine waste/tailings land cover in yellow. Landsat TM image of Cherokee County, Kansas (June 27, 1992). Bands 7-4-2 coded red, green, and blue.

Table 2. Error matrix for assessing accuracy of supervised classification.

	Mine waste/tailings	Other land cover	Row totals
Mine waste/tailings	8	42	50
Other land cover	1	49	50
Column totals	9	91	100

Overall accuracy = 57%

Mine waste/tailings producer accuracy = 89%

Other land cover producer accuracy = 54%

Users Mine waste/tailings accuracy = 16%

Users Other land cover accuracy = 98%

kappa (k_{hat}) = 14%

Mineral Characteristics

The band combination 3/4-3/1-5/7 (coded red, green, blue) shows the mine waste in the lower portion of the image with a green-yellow appearance which suggests that the waste materials have an iron oxide coating such as goethite (Peters and Hauff 2000) (Fig. 5). Similar color patterns in the image are crop land, so the reflectance values may be from the underlying soil. Band combination 3/1-5/4-5/7 attempts to separate iron oxides from ferrous minerals and clays (Fig. 6). The identified mining wastes near Galena (southeast) and the southern portion of the image range from red to yellow in coloration. The red coloration likely indicates iron oxide minerals, with little clay weathering. The image shows a more red color for the southern wastes indicating a mineralogical difference from the wastes in the vicinity of Galena. The more yellow coloration on some of the waste piles indicates the presence of clay minerals and likely carbonates (Peters *et al.* 1996). Band image 7/4-1/5-1/7 (not shown due to lack of contrast) was devised by Peters and Hauff (2000) to separate out high clay waste from iron minerals with little clay. The 7/4-1/5-1/7 band combination for Cherokee county is dominated by the red color values, which indicate areas of high iron content materials and little clay or altered rocks. Vegetation and water bodies in the image appear black in color.

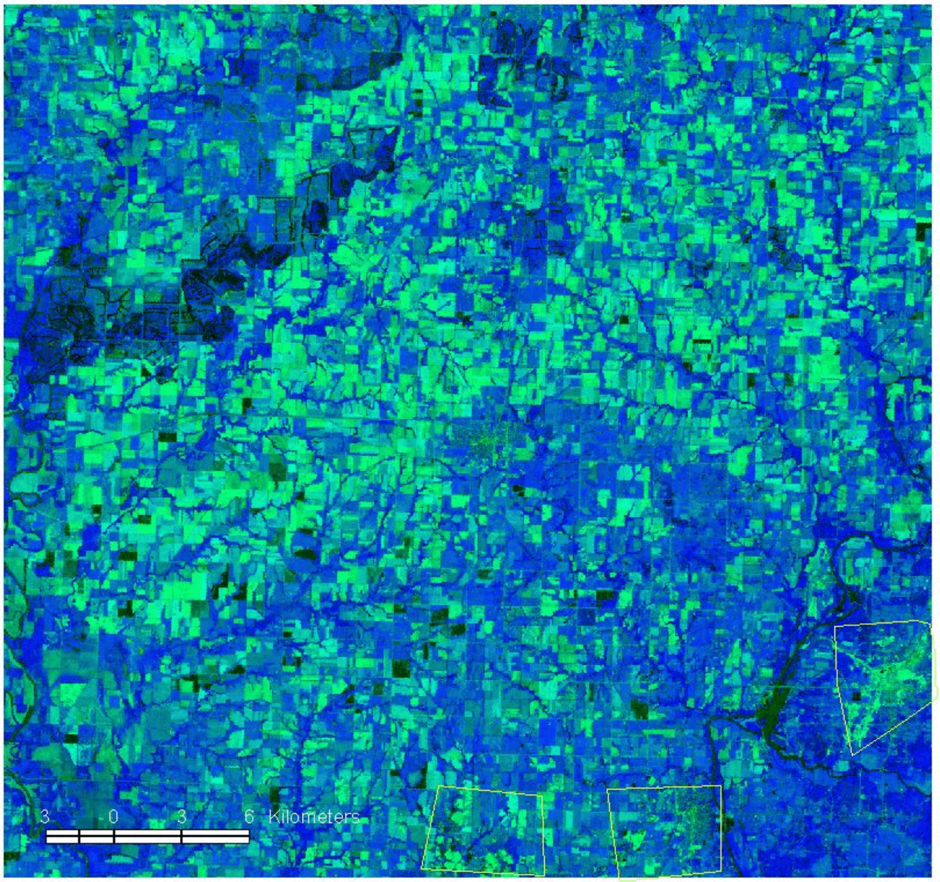

Figure 5. Landsat TM image of Cherokee County, Kansas showing band ratios 3/4-3/1-5/7. Exposed rocks and crop land are shades of green and yellow. The mine waste areas in the lower right are green to yellow in appearance with the more yellow areas indicating the presence of iron minerals. June 27, 1992.

Band combinations 5/7-3/1-4/3 (color coded red, green, blue) were utilized in an attempt to recognize hydrothermally altered bedrock, since much of the ore emplacement is thought to be related to hydrothermal deposits (Ragan 1996). The wastes located by the yellow outline boxes in are mostly green in color, which means that band combination 3/1 is dominating the visualization (Fig. 7). This further exemplifies the iron-oxide nature of the waste coatings. Clays and carbonates on the other hand, do not dominate the waste mineralogy signature (Peters and Hauff 2000).

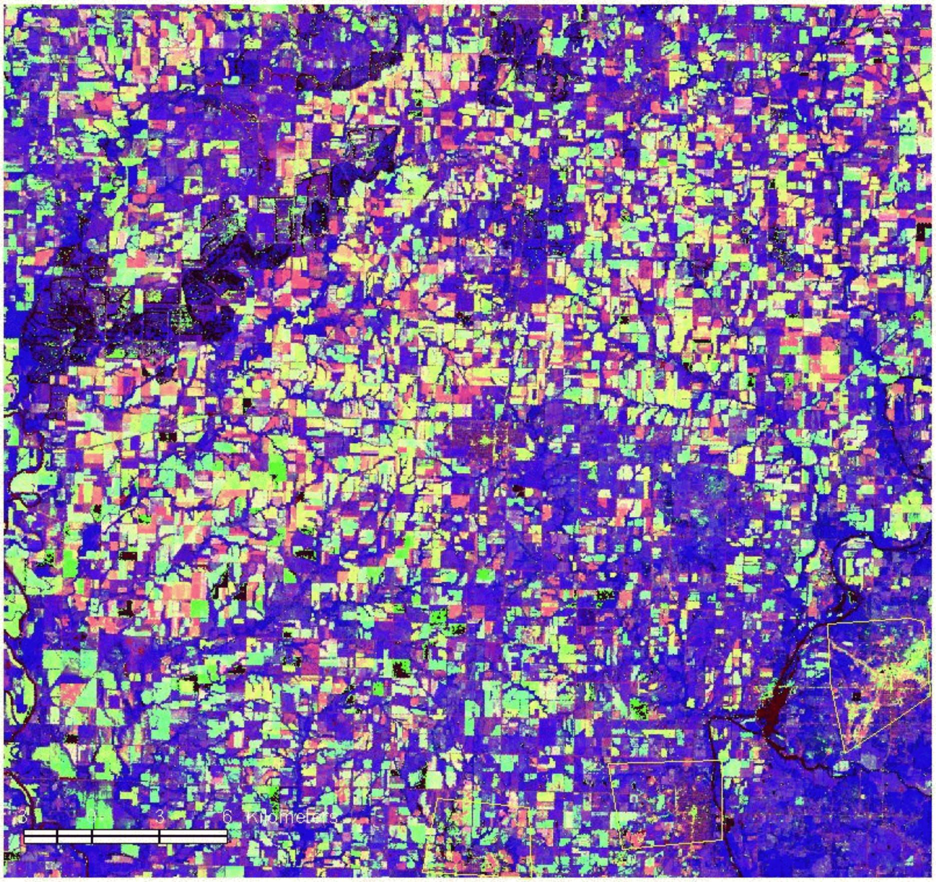

Figure 6. Landsat TM image showing band ratio combinations 3/1-5/4-5/7 for Cherokee County, Kansas (June 27, 1992). Note the red coloration of some of the waste piles in the lower right of the image indicating an iron oxide mineralogy. Ferrous mineral types are likely indicated in by the green coloration. Water bodies appear black.

The mineralogies of the ore types as identified by Brockie et al. (1968) include galena (PbS) as the mineral source for the lead ore, and sphalerite (ZnS) as the mineral source for the zinc ore. According to Carroll et al. (1996, p. 956), “The remaining tailings piles consist of mostly chert, a few weight percent calcite and dolomite, as well as residual sphalerite, galena, pyrite and marcasite.” Weathering of the sulfide minerals can produce acidic mine drainage, and the formation of iron oxides (Kent et al. 1987).

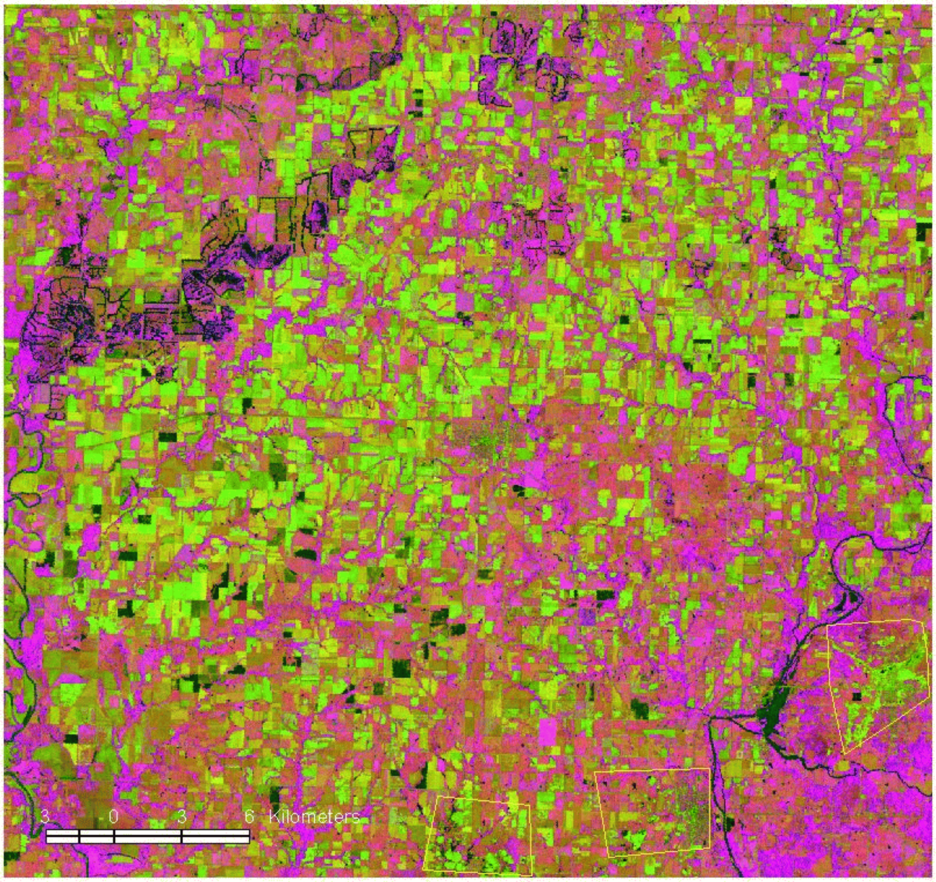

Figure 7. Landsat TM image showing band ratios 5/7-3/1-4/3 in an attempt to differentiate hydrothermal alteration. Some mine waste areas are shown within yellow boxes in the lower right. Cherokee County, Kansas (June 27, 1992).

Discussion

A comparison of the supervised and unsupervised land cover classification results (Figs. 3 and 4) with the locations of mine lands indicate that there is a good correlation between them regarding mine land sites. However, as shown in the error matrix tables (Tables 1 and 2), much of the other land cover types were also classified as mine wastes/tailings. Examination of Figure 2-1 in U.S. EPA (1986) which shows the location of abandoned mine lands in the vicinity of Galena, corresponds well with the classification of mine wastes/tailings in this area.

The spectral reflectance signatures of the mine waste were not different enough to allow for their separation from adjacent crop land in the region using Landsat TM imagery. As noted in the geology section, the surrounding soil/bed rock are composed of a cherty limestone or interbedded shales, sandstones, and coal beds in the northwest portion of the county. It is likely that the crop land vegetation cover allows for much of the soil spectral reflectance to be recorded by the Landsat sensors. Pasture areas likely have enough litter and vegetation cover to mask the soil reflectance properties. This would explain why the crop land areas have similar reflectance values to the waste piles based on the images presented, and the lack of separation with the classification methods used in this study. Though much of the mine waste/tailings areas are bare due to the high lead, cadmium and zinc levels which are phytotoxic (Lambert *et al.* 1999), these areas were not separable from many of the crop lands using this study's classification methods.

The mine wastes were very recognizable in the 7-4-2 band Landsat image (Fig. 2) and also in the orthophoto used for accuracy assessment. Though the classification methods used did not separate the crop land from the mine wastes, the Landsat TM image is still useful for identifying these waste areas. It is possible that another classification method such as textural classification (see Jensen 1996) may help to better differentiate these cover types.

The mineralogical analysis results were dominated by the iron oxide signature. This signature is likely from iron-rich mineral weathering coatings such as goethite. The wastes do not appear to have a high clay weathering content based on the image interpretations. In their work on stream sediments in the area, Carroll *et al.* (1998) found high iron sediments in portions of the area, but low iron sediments in other locations. The high iron content sediments were characterized by the presence of amorphous iron oxyhydroxides or poorly crystalline goethite at up to 65 percent by weight iron (Fe), with lesser amounts of quartz, calcite, dolomite, and sphalerite. Low iron content sediment was characterized by less than 10 percent iron by weight, and included quartz, calcite, dolomite, and sphalerite (Carroll *et al.* 1998). Though these sediments undergo some mineralogy changes in aqueous solutions, their makeup can be compared with the composition of waste pile mineralogies. This high and low iron content difference is not readily seen in the Landsat images.

Conclusions

The first hypothesis that metal mining waste/tailings in the county are recognizable in a Landsat TM image, and should have enough spectral differences from the surrounding land cover types to allow for mapping their distribution using supervised and unsupervised classification techniques is not fully supported by the results. Mining wastes/tailings were recognizable in the Landsat TM image, however, supervised and unsupervised classification methods could not readily distinguish mining wastes from nonmining land cover, especially crop lands.

The second hypothesis that the broad mineralogical characteristics of the identified metal mine wastes/tailings can be determined from the Landsat TM imagery is somewhat correct. However, the results only readily identified iron oxide mineralogies, and little further mineralogical detail.

Aside from these conclusions, use of Landsat TM data to identify the location of mining wastes/tailings in the Tri-State mining district is a useful exercise, and a general characterization of the mineralogy of the wastes can be made using the imagery.

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