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Cindy Bowes

Daniel Unger
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, unger@sfasu.edu

Kenneth W. Farrish
Arthur Temple College of Forestry, Stephen F. Austin State University, kfarrish@sfasu.edu

I-Kuai Hung
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, hungi@sfasu.edu

USING REMOTELY SENSED DATA TO QUANTIFY CONTAMINATED BRINE SITES IN SOUTHWEST TEXAS

Cindy Bowes, Daniel Unger, Kenneth Farrish and I-Kuai Hung
Arthur Temple College of Forestry and Agriculture
Stephen F. Austin State University
Nacogdoches, Texas 75962-6901
cinjoy@sbcglobal.net
unger@sfasu.edu
kfarrish@sfasu.edu
hungi@sfasu.edu

ABSTRACT

Although field checking of contaminated brine sites is relatively straight forward, the ability to field check a large and expansive area like southwest Texas can be time consuming and expensive. A more robust method is needed to accurately quantify brine contaminated sites in a more timely, efficient and cost effective manner. The overall goal of the project was to test a remote sensing methodology to accurately quantify the spatial extent and total acreage of contaminated brine sites in southwest Texas as a result of oil exploration. Landsat ETM+ data of southwest Texas were obtained and classified using supervised classification methodology with a maximum likelihood classification algorithm. Supervised classified was chosen since brine contaminated soil areas have distinct spectral signatures, especially in the dry season, which are easily distinguishable as training sites. Results indicate that Landsat ETM+ data can be an effective tool to use in quantifying previously unknown brine contaminated areas larger than 2 acres in southwest Texas to ascertain the spatial extent of contaminated brine sites as an aid in land reclamation/restoration.

INTRODUCTION

Since the advent of drilling for petroleum and natural gas in the United States, there has been a problem with the disposal of oilfield waste products. The majority of this oilfield waste is in the form of brine water (also called produced water) (Barrufet *et al*., 2005; Sirivedhin and Dallbauman, 2004). For every barrel of oil produced, approximately ten barrels of brine water are also produced (USGS, 1997; Barrufet *et al.*, 2005).

The disposal of this brine water has created some major environmental issues. Brine contaminated soils from petroleum production form "scars" on the landscape (Figure 1). These scars occur, because the high salt content of the brine has caused the soil in these areas to no longer support the growth of vegetation, causing long term damage to the flora and fauna of the area (Barrett 2002; Kinghorn, 1983). Without vegetation cover, these soils are subject to severe erosion, causing salt and sediments to impact downslope water bodies (McNally, 2006). To understand the impact on the environment and magnitude of the oilfield brine contamination problem there needs to be a true inventory of these sites.

Remote sensing with its ability to collect data systematically over large geographic areas is now critical to the successful modeling of numerous natural resource and cultural processes (Jensen, 2005). Because oilfield brine contaminated sites are typically isolated and difficult to access, it could be a highly useful tool in the identification of these sites.

METHODS

The purpose of this study was to assess the ability of satellite remote sensing to identify brine contaminated sites from petroleum production. Specific objectives were to locate known oilfield brine contaminated sites in west Texas on satellite imagery, use supervised classification of the satellite imagery to determine sites that are oilfield brine contaminated vs. sites that are not oilfield brine contaminated and assess the accuracy of the classification.

Trial study sites were in Reagan, Upton and Crane Counties in west central Texas (Figure 2). The training site

Figure 1. Scar of oilfield brine contaminated site.

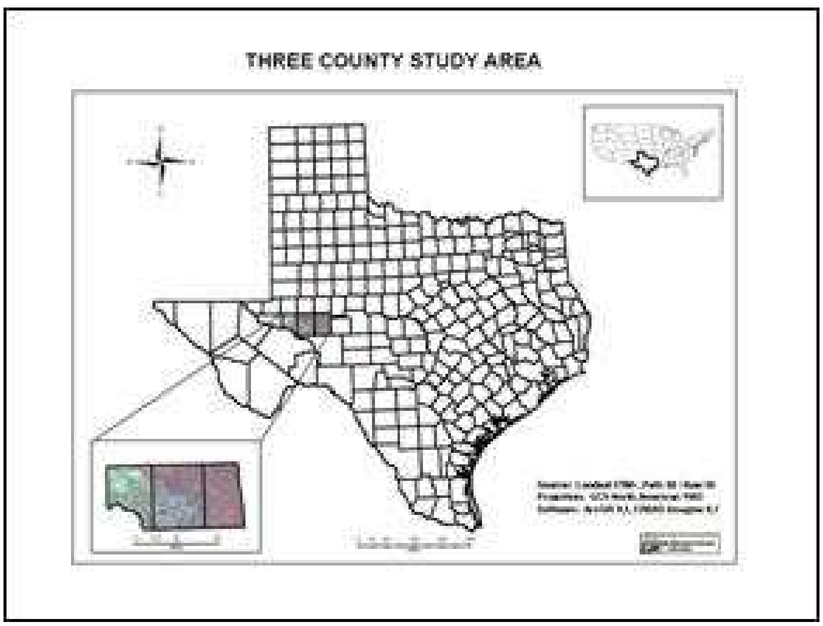

Figure 2. Study site in west Texas.

was the Texan Scar, within the Big Lake Oilfield located between the towns of Big Lake and Rankin in southwestern Reagan County, Texas (Figure 3). Two multispectral Landsat ETM+ (Enhanced Thematic Mapper) images of the Texon Scar study area were acquired from the Forest Resources Institute (FRI) website at www.fri.sfasu.edu. A summer image collected September 23, 1999 and a winter image collected February 22, 2003 of path 30 row 38 were acquired. Radiometric correction and geometric verification were performed on the data to acquire true spectral signatures of surface features and to verify geometric accuracy respectively.

Prior to supervised classification, and in consultation with petroleum geologists from the region, the identity and location of an existing oil contaminated brine site know locally as the Texon Scar was identified and used as a base for identifying the spectral signature of brine contaminated soil (Figure 4). A visual inspection of the Landsat ETM+ data from the summer of 1999 and the winter of 2003 were compared visually to determine which would be most likely to differentiate oilfield brine contaminated sites. The scar was barely visible in the summer image while highly differentiated in the winter scene; therefore the winter 2003 image was used in this study.

A Principal Components Analysis (PCA) was executed on the original six band data of the winter scene to derive a six band PCA image of the three county area (Figure 5). The six band PCA image was then classified into a land cover map of brine and non-brine areas using traditional supervised classification methodology with selected Texon Scar spectral signatures as training sites for all brine contaminated areas within the entire Landsat ETM+ image. The subsequent classified image was then clumped and sieved to attain a minimum mapping unit of two acres (Figure 6).

Once classification was completed, stratified random sampling design was utilized to ground truth the data. The three county study area was divided into land cover strata based on the remote sensing derived thematic map. A stratum was created using only the clumped and sieved pixels associated with oilfield brine contamination. Sites classified as brine contaminated, as well as a vector layer of roads, were super-imposed on county wide DOQQs. This aided in finding the location of these sites on the ground.

The Texon Scar was visited as well as eight other sites in the three county area that were determined during the classification process as being oilfield brine contaminated. In the meantime four randomly selected sites that did not

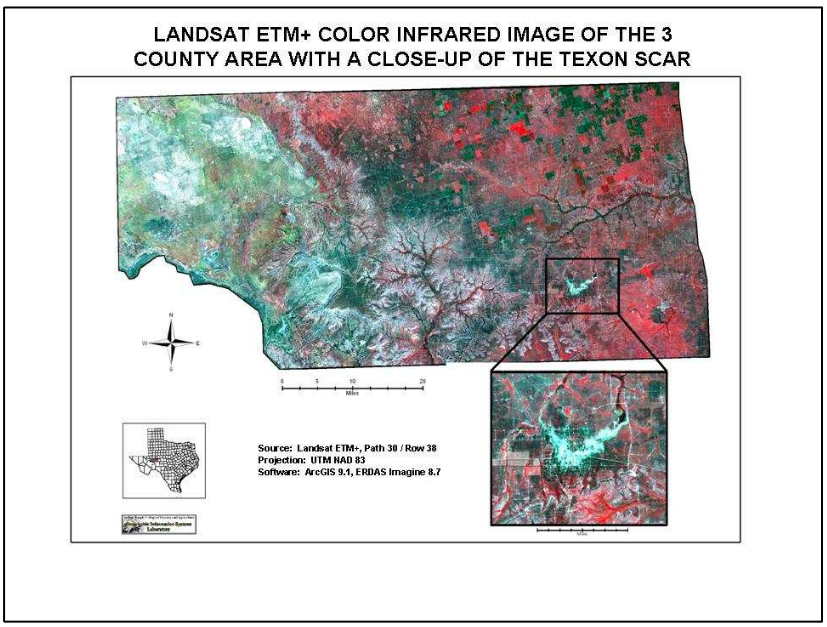

Figure 3. Location of Texon Scar in three county study area.

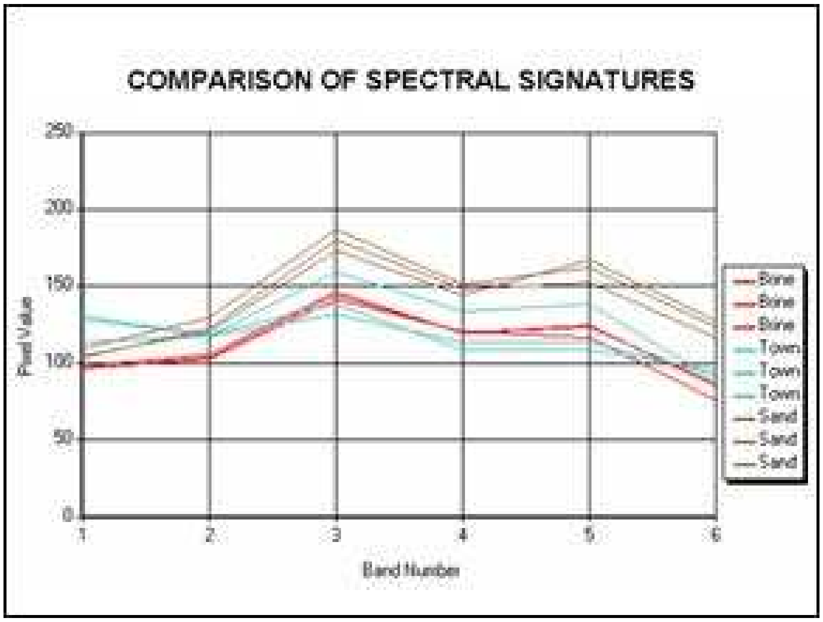

Figure 4. Spectral signature comparison.

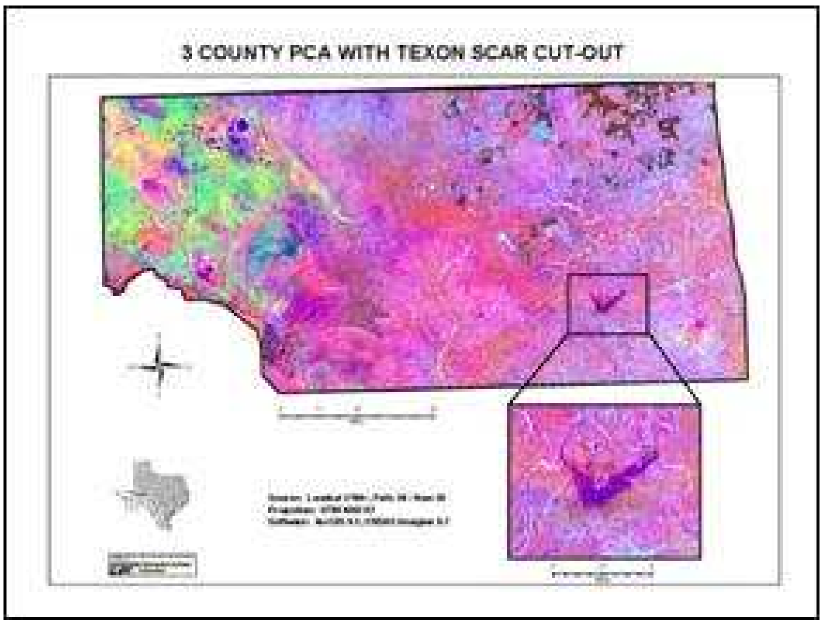

Figure 5. PCA image of the three county study area and Texon Scar.

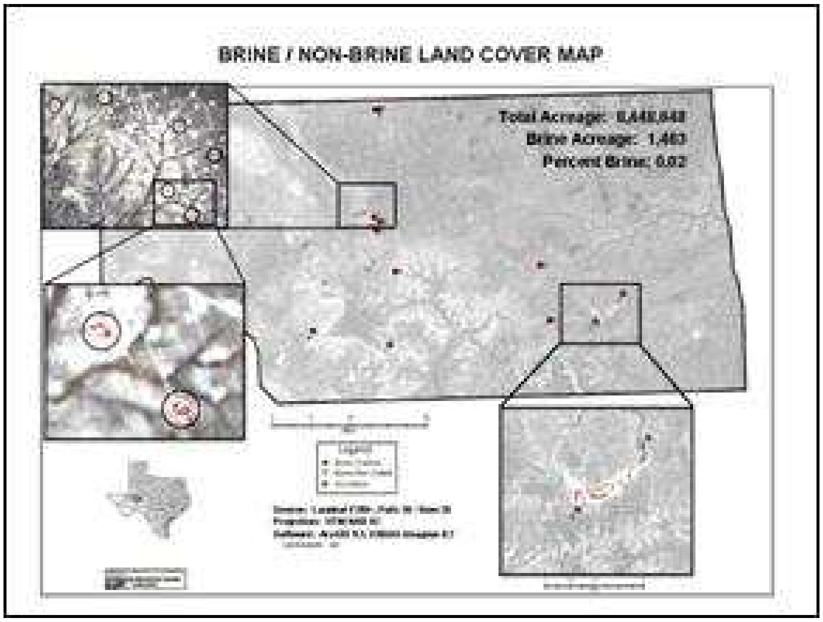

Figure 6. Land cover map of the three county study area and Texon Scar.

classify as brine (non-brine) were randomly selected and tentatively assessed as such during *in situ* visitation. These non-brine sites were confirmed as such with laboratory soil analysis. The limited number of sites visited was due to private property visitation constraints and the inaccessibility of other areas. An accuracy assessment of the resulting land cover map of brine and non-brine locations involved creating an error matrix indicating overall map accuracy, individual user's and producer's accuracy, a kappa statistic and a z-test for statistical significance (Figure 7).

RESULTS

Although satellite data acquired during the dry season were found more desirable for identifying irrigation-induced saline areas in arid and semi-arid areas of Thailand (Sukchan and Yamamoto, 2001; Farifteh and Farshad, 2002), this was not found to be the case in the study area of west Texas for oilfield brine contamination. Classification of oilfield brine contamination, based on the PCA of the Texon Scar winter image, identified 0.02% of the total three county study area as brine contaminated. After sieving for areas only greater than two acres, nineteen sites were identified as oilfield brine contaminated. These sites comprised a total of approximately 241 acres. Field observations were limited to sites based on feasibility of visitation due to owner and location constraints. Therefore, only eight of these sites were visited, as well as four non-brine contaminated sites. While white crusting on the surface at most sites classified as oilfield brine contaminated allowed for initial visual characterization as brine contaminated, the presence of brine was verified in laboratory via soil analysis. Overall map accuracy for the brine vs. non-brine land cover map indicated that overall land cover classification accuracy was 91.67%. The user's accuracy was 87.50% for brine sites and 100.00% for non-brine sites. The producer's accuracy for brine sites was 100.00% and 80.00% for non-brine sites. The overall kappa statistic for this study was 0.8235, indicating that the classification scheme was 82.35% better than what would be expected by chance classification of pixels alone. The *Z* statistic of 5.02, which is above the critical level of 1.96 for a confidence interval of 95%, indicated that the results are statistically significant and reproducible.

ERROR MATRIX

Count	*Reference Data*			
Class	Brine	Non-Brine	Row Total	*User's*
Brine	7	1	8	87.50%
Non-Brine	0	4	4	100.00%
Column Total	7	5	12	
Producer's	100%	80%		

OVERALL ACCURACY: 91.67%

KAPPA STATISTIC: 82.35%

Z STATISTIC: 5.02

Figure 7. Error matrix of the three county land cover map.

CONCLUSION

This research determined that the use of satellite remote sensing is a viable method of identifying oilfield brine contamination. Supervised classification of PCA derived data can be used to identify oilfield brine contamination based on an *a priori* known brine site in a Landsat ETM+ scene. Although studies based on satellite remote sensing are scene dependent, it is probable that the methodology used in this study could be utilized in other oil-producing areas of the world to identify brine contamination.

It is recommended that future studies utilize Landsat scenes from various other locations to test the successful methodology from this study. Additionally recommended are studies of the use of the PCA transformation to train pixels on a known oilfield brine contaminated site within a higher resolution satellite imagery scene, such as IKONOS (4 meter resolution), SPOT (20 meter resolution), or QUICKBIRD (2.5 meter resolution) to determine if the methodology is more robust as the spatial resolution of the sensor increases.

Since it is sometimes difficult to visit these sites due to land ownership constraints and out-of-the-way location, remote sensing seems to be the most viable method of determining the true spatial extent of the problem. Knowledge of the spatial extent and location of oilfield brine contamination is important for natural resource managers and regulators due to the negative effect these sites impose on the local environment. With the ability to remotely assess and quantify oilfield brine contaminated sites, time, cost, and efficiency will be improved; thus improving the management and remediation of these sites.

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