Using Satellite Imagery to Inventory of Erodible Lands in the Las Vegas Valley

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ABSTRACT

The rapid growth of the semiarid southwest U.S. has increased land disturbances and led to the destruction of natural soil crusts that inhibit wind erosion. For example, in the Las Vegas Valley, windblown dust contributes to exceedances of PM10 air quality standards. This paper discusses the spectral analysis methods that use satellite imagery to remotely identify different types of vacant land parcels. A suite of "training sites" and "validation sites" in two 10 km^2 pilot areas established firm relationships between the ground surface data and remote satellite images of the same area. The training sites were validated for soil stability by field observations of vegetation types and coverage, amount of loose surface material, surface crust strength, and presence of non-erodible elements.

Both aerial photography and geostationary satellite imagery (IKONOS, Landsat) were used in the analysis to identify vacant lands in the Las Vegas Valley. Spectral signatures were developed for a number of land categories including native desert and disturbed land. In addition, almost 200 miles of previously uninventoried private unpaved roads were identified and traffic was counted on a sample of the roads. Stratified random sampling, used with aerial photography, was used to generate reference data for accuracy assessment.

The analysis of remote imagery and associated "ground truthing" has resulted in the development of an inventory of vacant lands according to surface characteristics. Land areas of native desert, disturbed vacant land, stabilized vacant land, and private unpaved roads were documented in GIS layers that provide the basis for calculating wind generated emissions of suspended wind-blown dust.

INTRODUCTION

The purpose of this study was to develop an area inventory of vacant lands and private unpaved roads in Hydrographic Basin 212 consisting of 1,524 square miles within the Las Vegas Valley, as defined by Nevada State Plane coordinates. The vacant land categories of interest included native desert, disturbed vacant land, and stabilized vacant land, Prior wind tunnel studies of these land categories have resulted in algorithms for estimating PM-10 emissions in the form of windblown dust, reflecting differences in soil stability. Mapping of these land areas was necessary for the continued development of an accurate PM_{10} air emission inventory for Clark County The methodology for developing this inventory used multi-spectral satellite imagery and ground truthing to develop unique spectral signatures for each of these land categories within Hydrographic Basin 212.

The development of unique spectral signatures for each land category untilized a computer algorithm called supervised classification. This algorithm requires a suite of "training sites" that are representative of the land categories and the associated soil stabilities. The training sites were established through aerial photography and field evaluation, ensuring that the training sites accurately represented the soil stability categories. Additional subcategories such as urban landscape, drainage areas, and concrete were developed primarily to eliminate these stable land areas from the overall land area of interest and enhance accuracy. Several classification schemes were evaluated, but the Mahalanobis distance scheme proved to be the most effective for this particular project.

An accuracy assessment was performed to quantify the success of the supervised classification. Reference or validation sites were derived from field observations, and were also obtained from aerial photography and map data. An error matrix was developed to indicate the mapping accuracy of each land category by showing the percentage of correctly classified pixels.

The four main categories of land surfaces considered in this project were: (1) native desert, (2) disturbed and unstable vacant land, (3) disturbed and stabilized vacant land, and (4) private unpaved roads that had not been identified in existing Clark County data. Unpaved roads were identified through high-resolution aerial photography that proved to be more effective than satellite imagery. In addition, private unpaved average daily road traffic (ADT) was determined using traffic counters at selected locations. Both pneumatic and magnetic counters were utilized with data loggers. At each site, traffic counts were obtained on three days, including one weekend day.

The strategy for performing this project utilized a pilot study to assess all elements of data gathering and analysis before proceeding with the main study.

- Pilot Study (two 100-km^2 areas that covered predominant soil types within HB 212)
  1) Utilize limited study area to develop and test predictive algorithms derived from satellite imagery.
  2) Identify training sites for specified vacant land categories.
  3) Ground truth the traning sites to verify soil stability condition.

- Main Study (Rest of HB 212)
  1) Perform supervised classification of satellite imagery for full study area.
  2) Identify and characterize verification sites for accuracy assessment of supervised classification.

The inventory of land areas for soil stability using satellite imagery was initially to be based on high-resolution imagery from either the IKONOS or Quickbird satellites. Due to the significant cost of the imagery and the many uncertainties that had to be resolved in obtaining and managing the data in this project, it was decided to utilize a pilot study of relatively small areas before attempting to study the entire hydrographic basin.

During the evaluation of the first pilot area, imagery from the IKONOS satellite was used as well as Landsat TM (Thematic Mapper) imagery for comparison. This analysis revealed that the greater spatial resolution of IKONOS actually was a complicating factor in classification of the larger land areas of interest because of large pixel-to-pixel variation. Landsat, however, provided an inherent averaging of the minor variations in surface conditions across its 30-m pixel size. In addition, Landsat has higher spectral resolution, i.e., six visible/near-IR spectral bands compared to IKONOS's four bands.

TRAINING SITES

Training sites were established through aerial photography and field evaluation, ensuring that the sites accurately represented the land and associated soil stability categories. Ground truthing at each training site was completed within 48 hours of imagery acquisition to ensure the conditions did not change between the time the imagery was obtained and the ground measurements were taken. The training sites focused on primarily on the BLM disposal area (the developed area of the Las Vegas Valley). Figure 1 shows the BLM disposal area within HB 212. Field data were collected only during dry conditions (i.e., no precipitation for a period of 5 to 7 days prior to collection) based on weather data from McCarran International Airport.

Training and verification test locations were selected to represent surface uniformity over an area of approximately 60 m x 60 m in size (equivalent to 4 Landsat pixels). Some training sites were used to develop the spectral signatures and others were used as verification sites for testing the reliability of the spectral signatures. The Pilot Study was used to develop the most efficient ways to perform supervised classification before final classification was attempted. The Pilot Study also allowed the project team to evaluate and refine the ground truthing methodology and data collection forms, and understand the complexities of satellite imagery acquisition. The satellite imagery was obtained only for cloudless days.

After the Pilot Study was successfully completed, the most recent Landsat satellite imagery was purchased. This set of satellite imagery was processed to complete the inventory of vacant land. Twenty-four additional training sites were then used to develop the classification algorithms over wider expanses of HB 212. It was critical to minimize the time between imagery collection and ground truthing in order to minimize the likelihood of uncontrolled events changing the land surface. Such events include rainfall, wind events, or human activity disturbing the surface. Digital photographs and video were taken at each site to document soil condition, vegetative cover, and surrounding land area.

TEST METHODS

Ground truthing included the drop ball test, the rock test, and the threshold friction velocity (TFV) test as described in Section 90 of the Clark County Air Quality Regulations. The TFV was only done when applicable, i.e., when there was sufficient loose material on the surface to perform the test and if the rock test fails. In addition, an enhanced version of the drop ball test using a five-point penetration index was used to better characterize the soil crust.

Each test site (e.g., 3600 m^2) was tested three times each in randomly selected areas. Each of the three "test" areas within a training site is defined as 1-meter square per the Clark County regulations. Within each test area, the drop ball test will be done five times in a 30 cm x 30 cm (one-foot) square area in the lower left-hand corner of the 1-meter square area, the rock cover test one time, and the TFV one time, as applicable. The average of the replicate tests is used to characterize each training site. Table 1 presents the number and type of training sites that were characterized.

Figure 1. BLM Disposal Area within Hydrographic Area 212

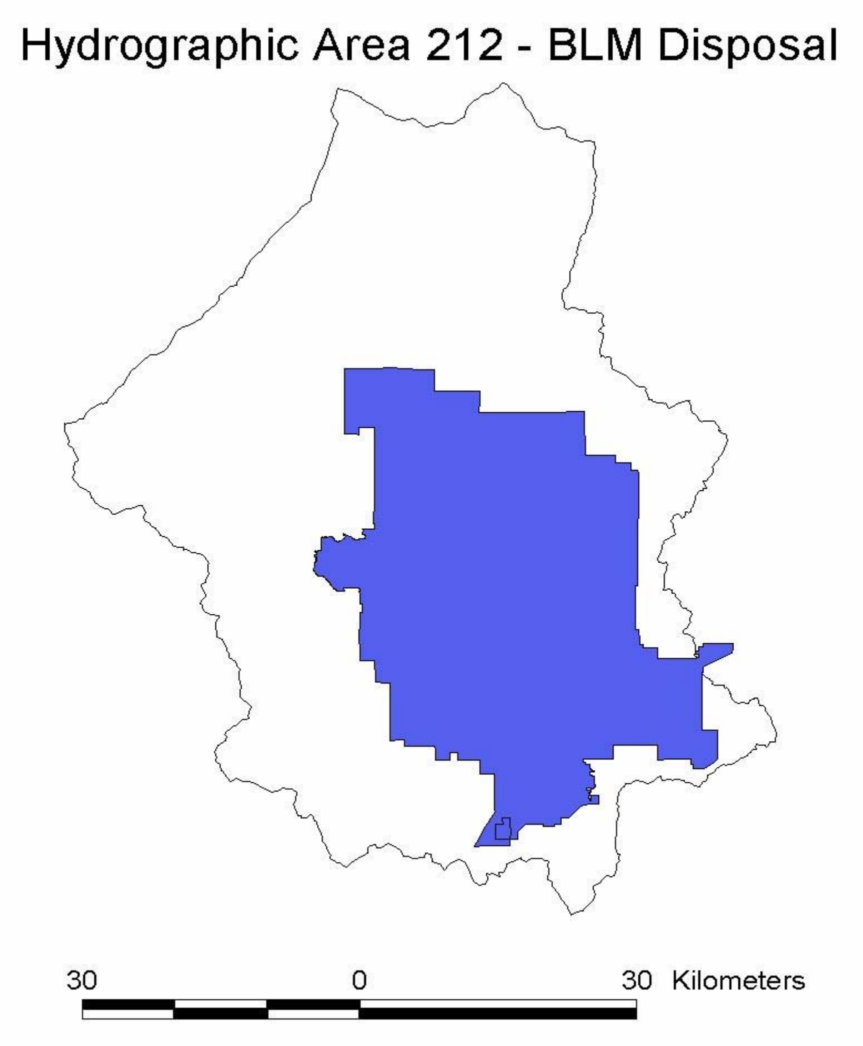


Table 1. Pilot study sites.

Type of Land Surface	No. of Sites
Disturbed unstable land	4
Native desert	5
Disturbed stable land	18
Unvegetated rocky surface (e.g., washes)	Several by aerial photographs
Anthropogenic areas: urban landscaping and asphalt	Several by aerial photographs
Unpaved roads	30
Water soaked areas (construction watering or heavy rains)	4

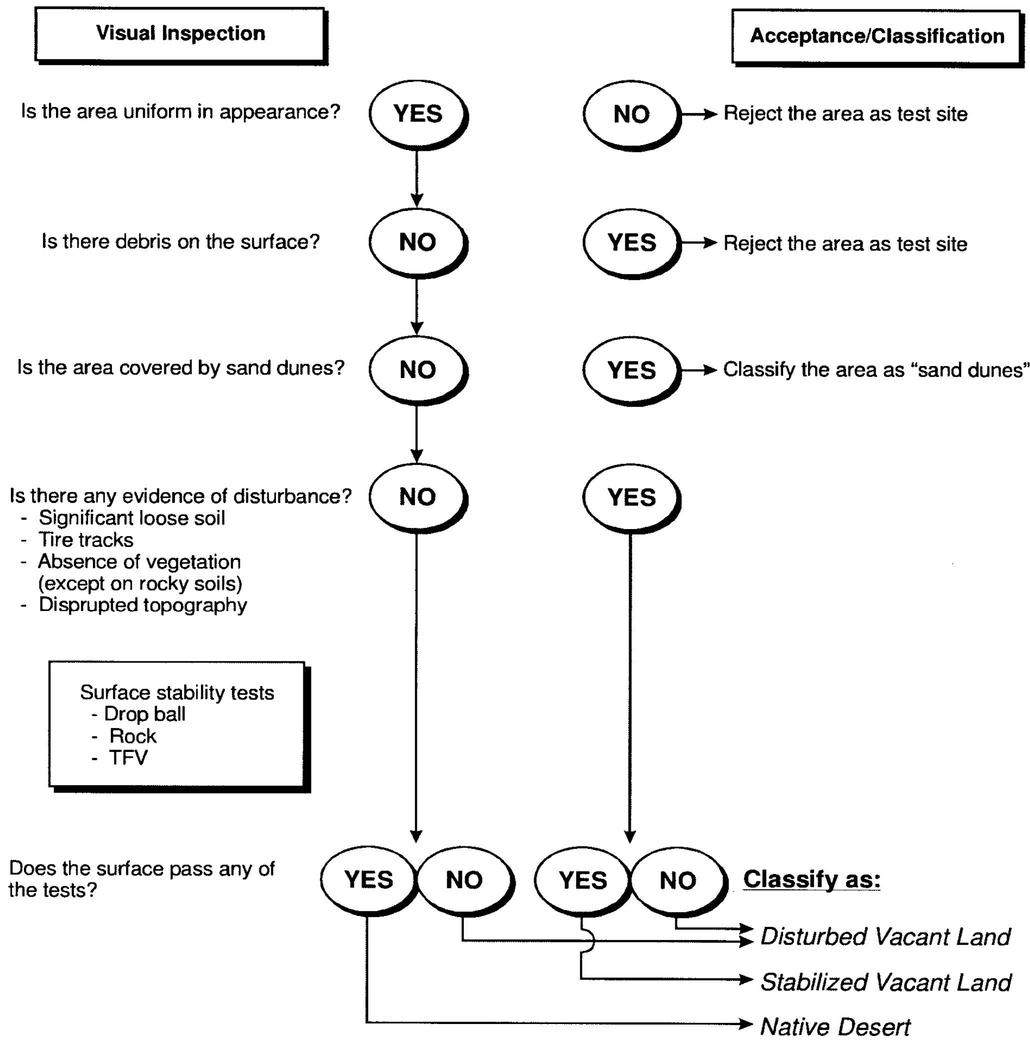
Native desert is defined as desert land in its natural state with no evidence of disturbance by anthropogenic activities. Native desert is characterized by (a) stable soil that is highly consolidated and (b) natural vegetation that is scattered across the surface except in wash areas with rocky surfaces. Typically native desert soil is impregnated with small rocks that in conjunction with natural mineralogical cementation form a desert pavement. In any case, the soil is crusted so that it passes the ball drop test (i.e., the ball does not penetrate the crust and form a crater containing loose dust). Even if there are small soil areas that do not pass the ball drop test, these areas are likely to pass the rock test (more than 20 percent coverage with non-erodible elements such as rocks or stones larger than 1 cm). Finally, any pockets of loose soil are likely to pass the threshold friction velocity test (TFV equal to or greater than 100 cm/sec). It should be noted that small amounts of loose dust may have been deposited on stable soil crust (especially in wind-depletion shadows of vegetative structures) during or after high wind events, and may have TFV values less than 100 cm/sec. However, such amounts are usually much smaller than the minimum significance threshold required for the TFV test (20 g/100 cm^2) based on engineering judgment, so that the test result is considered a pass.

Sand dunes in native desert environments constitute a special case because they are inherently unstable and continue to erode as long as high winds prevail. Surface disturbance of sand dunes does not affect their behavior as an unstable surface material.

Disturbed vacant land is native desert that has been disturbed by removal of vegetative groundcover and soil surface layers such that the natural crust on the soil is destroyed. Typically this occurs in association with construction or other land development activities. Disturbed land by definition is characterized by unstable soil, i.e., unconsolidated soil that is unprotected against wind erosion. In order to classify vacant land as disturbed, the soil must fail all three tests conducted in sequence: the drop ball test, the rock test, and the TFV test.

Stabilized vacant land is native desert that has been disturbed, but subsequently stabilized by natural phenomena or anthropogenic measures. Stabilized land by definition is characterized by stable soil, i.e., soil that is protected against wind erosion. If the soil is sufficiently rocky (such that it passes the rock test or the TFV test), it remains stable, even immediately after mechanical disturbance. If the soil is not sufficiently rocky, it may take years to reform a stable surface by natural processes. In order to classify vacant land as stabilized, it must pass one of three tests: 1) the drop ball drop test, 2) the rock test or 3) the TFV test. When these tests are conducted in sequence, one passing test negates the need for performing any additional tests. Figure 2 presents a decision tree for vacant land classification

Figure 2. Decision tree for vacant land classification



SATELLITE IMAGERY SELECTION AND PROCESSING

IKONOS satellite imagery of the north pilot area was obtained for evaluation as part of the Pilot Study. In addition, Landsat TM data was purchased because of its low cost and applicability to the large, relatively homogeneous area outside the BLM disposal area. One Landsat scene encompasses not only all of HB 212, but all of Clark County, which is four times larger.

Landsat TM imagery was obtained, and the registration accuracy was verified using aerial photography. Use of Landsat TM imagery proved to be much more useful and cost-effective than high spatial resolution imagery (IKONOS or QuickBird) that lacks the additional infrared wavelength bands. High spatial resolution imagery can pick up micro-features (e.g., vehicles, large trash piles, individual rocks) that are difficult to categorize by selective classification and have only localized effects on wind erodibility. The larger pixel size provided by the Landsat TM sensor (30m x 30m) is more appropriate for land areas with micro-features that do not affect wind erodibility.

The larger pixel size for Landsat TM provides an averaging effect that is very useful for characterizing the vast areas of native desert outside of the BLM disposal area. Because there is no advantage to distinguishing subcategories of native desert with varying amounts of vegetation, the averaging of reflectance across different vegetative densities greatly simplifies the process of identifying and mapping native vegetation.

In addition, the extra IR wavelength bands available from Landsat TM have been demonstrated to be very useful in distinguishing senesced vegetation and soil moisture. Landsat TM in conjunction with QuickBird is being used effectively in evaluating vegetation and other dust control strategies at Owens Dry Lake in California. The other obvious advantage of Landsat TM imagery is the much lower cost, which makes periodic updates of land category inventories economically feasible.

SPECTRAL ANALYSIS PROCEDURES

The four categories of erodible land surfaces considered for this project were (1) native desert, (2) disturbed vacant land, (3) stabilized vacant land, and (4) private unpaved roads or other unpaved roads that have not been identified in existing Clark County data. A surface drainage category was added as a subcategory of native desert, because of the unique spectral profile of surface drainage.

Because of the sensitivity of disturbed vacant land to soil chemisty, unique spectral signatures for this category could not be determined. As a result, other categories with unique signatures were added, so that that disturbed, unstable land could be determined by difference. For example, barren shadow, which is largely comprised of mountainous and/or rock areas plus shadowed areas, was found to have a unique spectral signature. In addition, large concrete surfaces and urban areas (dominated by rooftops) were also added. Finally, urban vegetation was added as a category by using the spectral signature of the green areas (e.g., golf courses) in the Landsat TM imagery.

Supervised Classification

Multi-spectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. The analyst closely controls supervised training. In this process, image pixels that represent the land cover features listed above are selected. These pixels are identified primarily from ground truth data, with available GIS layers as ancillary data.

It is important that training samples be representative of the classes that are being identified. The selection of training samples depends largely upon knowledge of the data, of the pilot study area, and of the classes to be extracted. By identifying representative ground truth sites, the computer system is "trained" to identify pixels with similar characteristics. If the classification is accurate, the resulting classes will represent the land surface categories within the Landsat TM data.

Once a set of reliable signatures has been created and evaluated, the next step is to classify the data. Each pixel is analyzed independently. The measurement vector for each pixel is compared to each signature, according to a decision rule, or algorithm. Pixels that pass the criteria established by the decision rule are then assigned to the class for that signature.

The Mahalanobis distance classifier is designed so that clusters that are highly varied will lead to similarly varied classes, and vice-versa. For example, when classifying urban areas, typically a class whose pixels vary widely, correctly classified pixels may be father from the mean than those of a class for water, which is usually not a highly varied class (Swain and Davis, 1978). The classifier was chosen because it was superior in its ability to classify the highly varied land cover types in Hydrographic Basin 212.

Table 2 summarizes the land classifications for HB 212 derived from the classified imagery based on the Landsat view of June 26, 2005.

Table 2. Land categories.

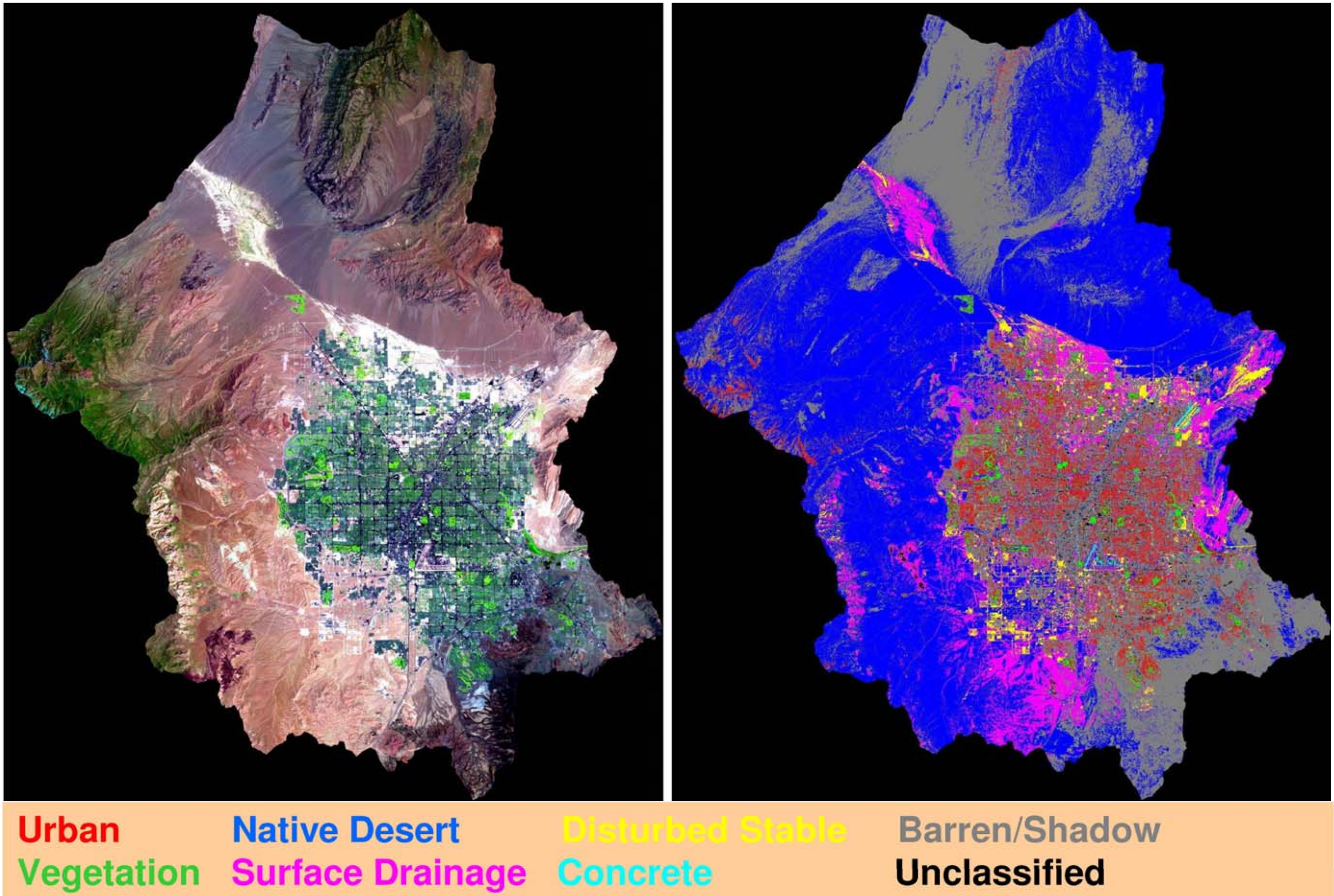
Land Category	Percent of HB 212	Square Kilometers
Native Desert	48.1	1,897
Disturbed (Unstable)	< 1.1	< 45
Disturbed Stablilized	3.1	1223
Drainage	9.1	357
Barron/Shadow	33.1	1307
Urban	4.9	192
Concrete	0.7	26

The amount of disturbed unstable vacant land is significantly less than previously reported. This is attributed to several factors:

1) A probable over-estimation in the past given the qualitative methods available at that time.
2) The success of the enforcement program requiring contractors to utilize stabilization techniques during construction.
3) The higher than average rainfall in the Valley during 2004 and 2005.

Figure 3 shows the supervised classification of the Landsat TM imagery using Mahalanobis Distance classification. The left part of the figure is the visible image from the satellite, and the right part of the figure shows the classified land areas.

Figure 3. Mahalanobis supervised classification of Landsat TM Imagery for HB 212



Accuracy Assessment

An accuracy assessment was performed to quantify the success of the supervised classification. Reference or validation sites were derived from field observations, and also were obtained from aerial photography and map data. An error matrix indicates the mapping accuracy of each soil stability category by showing the percent of correctly classified pixels.

Table 3 provides the error matrix for the classification process. Error matrices are very effective representations of map accuracy because the individual accuracies of each map category are plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map. A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs. Overall accuracy is the sum of the major diagonal (i.e., the correctly classified pixels or samples) divided by the total number of pixels or samples in the error matrix (Congalton and Green, 1999). The overall accuracy for the classification of HB 212 in this project is 89% (313/350).

Table 3. Classification error matrix.

Error Matrix

Reference Data

Classified Data	Barren/ Shadow	Concrete	Disturbed Stable	Vegetation	Natural Drainage	Urban	Native Desert	Row Total
Barren/Shadow	43					6		49
Concrete		45						45
Disturbed Stable		5	50		18			73
Vegetation				50				50
Natural Drainage					31			31
Urban	7				1	44		52
Native Desert							50	50
Column Total	50	50	50	50	50	50	50	350

Overall accuracy = 313 / 350 = 89%

Identification of Private Unpaved Roads

A second phase of the project involved the identification of unpaved roads in HB 212 which were not already in the Clark County GIS. Roads were identified through 2-foot pixel aerial photography supplemented by field surveys. By definition, roads had to be a minimum of 22 feet wide. A total of 158 miles of unpaved roads were identified.

A sample of 30 road segments was selected on which to perform traffic counts. The 30 segments were selected to be representative based on usage. All 30 segments were in the urban area and in areas of expanding home building. Many of these roads will be paved as the development is completed. Excluding three sites with ADT (average daily traffic) counts exceeding 150, the average daily traffic count was 36.

CONCLUSIONS

The methodology for developing this inventory used multi-spectral satellite imagery and ground truthing to develop unique spectral signatures that allowed mapping of land areas of the stated surface characteristics within HB 212. The important conclusions drawn by the investigators are as follows:

- The Landsat satellite imagery is more cost-effective for this purpose than high spatial resolution imagery, and avoids classification errors due to confounding effects of small pixel size.
- High-resolution aerial photography is an important tool to supplement imagery, because of its usefulness of providing broad-scale ground truthing.
- There is far less unstable land in the Las Vegas Valley than previously thought. The enforcement of regulations controlling construction-related dust has significantly decreased unstable land across the Valley.
- Soil chemistry is an important variable in classification of disturbed, unstable land. Mapping of this land category is not feasible because of small training sites and soil diversity.
- Soil erodibility is not closely correlated with Wind Erodibility Groups (WEG), but more so the condition of the surface. WEG classification is based on deep soil horizons rather than surface soil characteristics. In turn, the chemistry of surface soil is homogenized by deposition of mixed soils following wind erosion events.

ACKNOWLEDGMENTS

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REFERENCES

1 Clark County Nevada Air Quality Regulations, Section 90 – Fugitive Dust from Open Areas and Vacant Lots, Amended July 1, 2004.

2 Clark County Department of Air Quality and Environmental Management (DAQEM), Nevada Air Quality Designation Boundary Recommendations for the 8-Hour Ozone NAAQS for Clark County, Nevada, Las Vegas, Nevada, July 2004.

3 Congalton, R.G.; K. Green, *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*, CRC Press, 1999.

KEYWORDS

Remote Sensing; Wind Erosion, Soil Stability; PM Emissions; Spectral Analysis.