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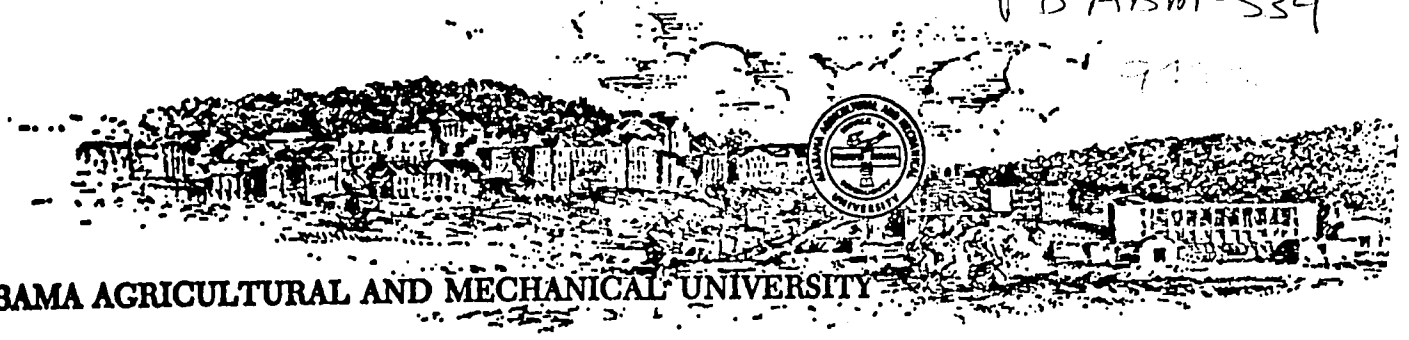

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December 23, 1995

Mr. David Rakes
HBCU Research Coordinator
U.S. Agency for International Development
Center for Human Capacity Development
G/HCD/PP, Room 600, SA-18
Washington, DC 20523-1815

RE: Grant No. PCE-5053-G-00-3044-00, 1995 Year End Report

Dear Mr. Rakes:

The succeeding paragraphs and appendixes serves as the year end report for FY'95 of the above referenced grant.

The activities of the past year have been spent analyzing data and writing manuscripts from the tasks we identified during our trip to Botswana and reported in previous quarterly reports.

The activity involving linking soil attribute data with spectrally-derived land cover classification of Botswana's Southern District has been completed. A manuscript entitled "Correlation of soil attributes with spectrally-derived land use classes of south central Botswana" authored by T. L. Coleman, M. Nkambwe, S. Ringrose, M. D. Nellis, and C. E. Bussing was prepared and presented at the 1995 annual meeting of the Soil Science Society of America held October 29 - November 3, 1995 in St. Louis, MO. The manuscript was also submitted to the Journal Remote Sensing of Environment for peer review and publication. A copy of the manuscript is attached as Appendix A.

The tasks headed by Dr. Nellis and Dr. Bussing are progressing as they continue to analyze two dimensions of the field data and related satellite data. One of the tasks involves an overview analysis of the rural land use system in the Southern District, and the other involves a multi-temporal analysis of linkages between grazing intensity indices and multispectral satellite data sets. A manuscript from some of this work has been prepared and accepted for presentation at the American Geographers meeting in Charlotte, NC.,

scheduled for April 1996. A copy of the progress report of Dr. Nellis and Dr. Bussing and the presentation abstract entitle "Spectral and Spatial Dimensions of Rural Land Use Systems in the Southern District of Botswana" is attached in Appendix B.

The tasks headed by Dr. Nkambwe and Dr. Ringrose are also progressing. Dr. Nkambwe informed me by fax from Stockholm University on December 21, 1995 that he anticipate to have a draft of a manuscript from the study involving land use conflicts in the Southern District prepared by March 1996.

I am still hopeful that we will complete all of the work by April and the final report by June 1996.

Sincerely,

Tommy L. Coleman

Tommy L. Coleman, Ph.D.
Professor and Director of HSCaRS
Principal Investigator

cc: Dr. Nellis
Dr. Bussing
Dr. Nkambwe
Dr. Ringrose

Appendix A.

Correlation of soil attributes with spectrally-derived land use classes of south central Botswana

CORRELATION OF SOIL ATTRIBUTES WITH SPECTRALLY-DERIVED LAND USE CLASSES

by

T. L. Coleman[1], M. Nkambwe [2], S. Ringrose[2], M. D. Nellis[3] and C. E. Bussing[3]

Submitted to:

Remote Sensing of Environment

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ABSTRACT

The primary objective of this study was to investigate relationships among soil spectral properties and selected soil physical properties used in differentiating soil mapping units and land use classes in south central Botswana, Africa. Thirty-four sites were selected along multiple transects which dissect Botswana's Southern District. This resulted in one hundred and two samplings units. The surface soil parameters investigated were structure, color, texture, degree of erosion, crusting, and compaction. Additionally, grazing intensity, vegetation percentage, and the normalized difference vegetation index (NDVI) were used in the analyses. Spectral data were extracted from six three-band Landsat Thematic Mapper (TM) quarter scenes (TM bands 2, 3, and 4) recorded June 23, July 7, and August 1, 1994. Land use classes of each quarter scene were determined using an unsupervised classification routine of the Earth Resource Analysis System (ERDAS) Imagine Software and verified using ground reference data.

Significant correlations were found among the spectral data, surface soil physical properties and surface soil conditions investigated in this study; however, the amount of variability explained was low. Seven of the soil mapping units and two land use classes were accurately differentiated at levels of 100%. The communal grazing land use class was the only class differentiated at a level less than 66%. The

overall classification accuracy for differentiating the soil mapping units and land use classes was 88.2% and 67.6%, respectively. Prediction equations for estimating surface soil conditions such as compaction, crusting, and grazing intensity were successfully generated from the spectral data and surface soil physical properties. The equations for surface soil compaction and grazing intensity accounted for 36.7% and 76.9% respectively, of the variability in the data. Significant relationships were also found among NDVI, vegetation percentage, and the surface soil properties investigated. The relationship for estimating NDVI was strongly influenced by the TM spectral bands, surface soil color, erosion, and texture. The predicition equation accounted for 81.2% of the variability in the data.

List of Keywords: Soil properties, variability, spectral, spectra, radiance, land cover

INTRODUCTION

Current as well as historic information on land use activity in Botswana is critical for resource managers to effectively manage the country's natural resources. Land use planning plays a key role in the decision-making process at all levels of government. According to Hunter (1988) it provides a logical framework for the development and coordination of extension services throughout the country. It rationalizes the provisions of infrastructure and social services and the structuring of areas under rural development programs. It provides a framework of collecting and assessing resource data and should help to reconcile institutional boundaries.

Studies have shown that remotely-sensed data from satellites can be used to generate land cover maps on a regional scale (e.g. Hill and Megier, 1988; Shimoda et al., 1988; Coleman et al., 1992). Satellite remotely-sensed data as a source for generating land use maps offers a unique advantage over the more traditional aerial photographic means of generating land use maps. Satellites afford land use managers an opportunity to utilize computer image processing techniques and repetitive coverage of an area to assess temporal changes in a quantitative manner. However, there are also inherent problems associated with the use of computers to generate land use classes from satellite imagery. These problems are associated with pixels that have two or more land cover classes within their boundaries. In an attempt

to alleviate these problems Lucas et al. (1990) integrated topographic data from a geographic information system (GIS) to improve the classification accuracy of an object classification. They defined an object as an area where only one land cover type was expected. The results of the per pixel classification were used per object to determine the land cover type of that object. The object classification improved the overall accuracy of two agricultural regions by 12 and 20 percent. Gong and Howarth (1990) used a structural information band to increase the classification accuracy by 10.5 percent compared to a conventional maximum-likelihood classification. Cushnie (1987) used a pre-classification filtering method and median, mean and other low-pass filters to improve his classification accuracy by almost 20 percent. Others have used techniques of integrating satellite image data with cartographic data to improve classification accuracies (e.g. Goldberg et al., 1985; Goodenough et al., 1987; Jensen et al., 1984; Hodgson et al., 1987; Gugan, 1988; Zhou, 1989; Walsh et al., 1990; Ross et al., 1991). Still others have used two-and three-dimensional modeling techniques to assist in defining spectral classes (Berry, 1987; Burrough et al., 1988; Coleman, 1992).

Traditional means of using aerial photointerpretative techniques to produce land use maps have been very successful. However, the success of these efforts are dependent upon the quality of prints available for the study. A land use map of Botswana's Southern District was successfully prepared at a scale of 1:250,000 using

photographs collected in 1982 by Environmental Consultants of Gaborone, Botswana [Southern District Planning Study, 1988. N. H. Hunter (ed)]. The major land use classes identified were communal mixed farming, communal grazing, commercial grazing, wildlife management zones, residential, and industrial.

Soil mapping in Botswana is based on main units of parent material groupings which show a strong relationship with both soils and landscape (Remmelzwaal, 1988). The main system of classification used is the 1974 Food and Agriculture Organization (FAO) Legend of the Soil Map of the World (FAO/UNESCO, 1974) which is correlated with Soil Taxonomy (Soil Survey Staff, 1994) and the Revised Legend of the Soil Map of the World (FAO, 1988).

Several studies have shown that satellite spectral reflectance data can be effectively used to differentiate soils and soil properties in North America (e.g. Cipra et al., 1980; Latz et al., 1984; Coleman and Montgomery, 1987; Henderson et al., 1989; Agbu et al., 1990; Coleman et al., 1993) and Southern Africa (Ringrose et al., 1988; 1989). Multispectral satellite data have been effectively used for mapping vegetative landscapes of temperate regions (e.g. Horvath et al., 1984; Thompson et al., 1984; Lee et al., 1988; Coleman et al., 1990; Coleman et al., 1992) and the semi-arid regions of Africa and Australia (e.g. Ringrose and Matheson, 1991a; 1992; Matheson and Ringrose, 1994a; 1994b; Ringrose, et al., 1994; Nellis et al., 1995). Significant correlations among surface soil attributes, such as texture, color, moisture, and

organic matter content, and multispectral reflectance data have been found for both temperate, semi-arid, and the African Sahel regions (e.g. Ringrose and Matheson, 1987; 1991b; Coleman et al., 1993; Coleman and Tadesse, 1995).

The objectives of this study were to (i) determine if soil mapping units and land use classes of Botswana's Southern District can be differentiated using Landsat Thematic Mapper (TM) spectral data and (ii) identify the spectral band combinations and soil properties that could be used to estimate soil compaction, crusting, and grazing intensity in the area.

MATERIALS AND METHODS

Thirty-four sites were selected throughout Botswana's Southern District which provided a broad representation of its diverse land cover (Figure 1). Generally the sites were sampled along transects through various portions of the District at systematic intervals of 10 to 20 km. However, exact locations of cover change and transitions were noted. Each sampling site represented an area of 900 m^2 and was identified using a global positioning system (GPS) as well as other reference points such as road intersections in the District. In addition, odometer readings and directional headings were noted for each site. Other observation sites from key location points, e.g., villages, mine areas, boreholes, and cattle posts were also documented. At each site, the

number and height of trees, brushes/shrubs, and grasses were recorded. Grass density and stem clusters were sampled at the mid-point of each cell-side and at the center of each 30 x 30 m cell using a 50 cm quadrant frame. This was done in order to determine vegetation percentages and densities within the area. The major land use within the area was also recorded. Additionally, the grazing intensity within and around each site was determined and recorded as slight, moderate, severe, and very severe and coded as 1, 2, 3, and 4 respectively for use in the statistical analyses. The assignment of a grazing intensity category at each site was determined based on the amount of visible bare soil, evidence of soil erosion, indications of animal impact through trampling, and grass densities and heights.

Within each sampling cell a 50 cm quadrant frame was randomly dropped at three locations, and the soil structure, texture, color, evidence of erosion, crusting, and compaction were evaluated using local qualitative field techniques and legends used by the Soil Mapping and Advisory Service (Remmelzwaal, 1988; Husken, 1988). In order to use these data in a statistical evaluation for generating prediction equations they were assigned numerical values. Soil structure was recorded as loose/single grain, granular, subangular blocky, or stoney and given a value of 1, 2, 3, or 4, respectively. Soil texture was recorded as sandy/coarse, medium, or clayey/heavy and given a numerical value of 1, 2 or 3, respectively. Sandy/coarse texture corresponded to sand, fine sand, loamy sand and light sandy loam.

Medium soil texture corresponded to heavy sandy loam, loam, clay loam, and silt loam. Clayey/heavy soils texture corresponded to sandy clay loam, sandy clay, and clay. Soil color was recorded as light, medium, and dark and coded as 1, 2, and 3, respectively. Light soil colors corresponded to the Munsel color codes of 2.5YR 3/2, 10YR 5/3 and 2.5Y 3/2. Medium colors corresponded to codes such as 10YR 5/6, 7.5YR 5/6, and 2.5YR 5/8. Dark soil colors corresponded to Munsel codes of 7.5 YR 4/6, 5YR 5/8 and 2.5YR 3/6 or darker.

Soil erosion was characterized as slight, moderate, and severe according to the presence of rills and gullies and the visible reduction in soil material from underneath shrubs and low growing trees to areas not covered by vegetation. An area with a slight rating was given a value of 1, moderate a value of 2, and severe a value of 3. Soil compaction was characterized as none/slight, moderate, and severe and was coded as 1, 2, and 3, respectively. Compaction was determined based on the number of animal hoof prints present and crusting of the surface soil. No quantitative laboratory measurements were used to determine the actual degree of compaction or any of the other associated variables. Soil crusting was defined by the degree of cohesiveness of the surface soil particles. Soil crusting was recorded as none/slight, moderate, and severe and coded as 1, 2, and 3, respectively for use in the analyses. The soil mapping unit which corresponded with each sampling site was also recorded from the 1:250,000 soils map of the District (Figure 2).

Landsat Thematic Mapper (TM) data of the District were obtained from the Satellite Applications Centre, Pretoria, South Africa. Six TM quarter scenes were required to cover the District. Three of the scenes were recorded on June 23, 1994, two on July 7, 1994 and one on August 1, 1994. Based on previous work carried out by Dr. Ringrose and Dr. Nkambwe in the area, only TM bands 2, 3, and 4 were purchased and used in the analyses. The areas that corresponded to the field sites were identified from the GPS coordinates that were recorded for each site. The digital numbers (DN) of each of the sampling areas were extracted using the Earth Resource Data Analysis System (ERDAS) Imagine software housed on a Sun SPARC10 computer (ERDAS, 1995). The actual DN values of the georeferenced TM data were used in the analyses. The DN values were used because a previous study conducted by the senior author revealed that there were no advantages gained from converting the DN values to intensity of reflectance values (Coleman et al., 1993).

Descriptive statistics were computed by the elementary statistics procedures in the Statistical Analysis System (SAS) computer software (SAS Institute, 1994). The DISCRIM procedure in SAS was used to develop discriminant functions to classify each observation into one of the soil mapping units and land use classes. These functions were also employed to compare the ability of the TM spectral data and selected surface soil physical properties in differentiating among soil mapping units and land use classes of the District. In the DISCRIM procedure,

distance functions between the observation and the centroid of each population were calculated, and each observation was placed in the class from which it had the smallest generalized squared distance, assuming that each class has a multivariate normal distribution. The classification criterion was based on either the individual within-group covariance matrix or the pooled covariance matrix, taking into account the prior probabilities of the groups. The Chi-Square test was used to determine the covariance matrices that was used in the discriminant functions. Stepwise regression procedures were used to develop the models (linear equations) to predict surface soil conditions using spectral data and selected soil surface properties.

RESULTS AND DISCUSSION

Discriminant Classification of Soils and Land Use

The soil taxonomic and land use classifications of each of the sampling sites are given in Table 1. There were six soil mapping units identified using the FAO soil classification system which translated to eleven mapping units using Soil Taxonomy (Soil Survey Staff, 1994). Four land use classes were included in the thirty-four sampling sites. The association of the variables was measured by generating a coefficient of correlation matrix, which showed highly significant correlations among the TM spectral data and surface soil physical properties observed (Table 2). The homogeneity test of the within-group covariance matrices for differentiating the soil mapping units

was found to be not significant at the 0.100 probability level; therefore, the pooled covariance matrix was used in the discriminant function. The within-covariance matrices were used in the discriminant functions generated from the variables used to differentiate the land use classes because the Chi-square value of 1669.5 was significant at the 0.0001 probability level. The soil mapping units and land use classes used in this study were differentiated at a high level of accuracy using the discriminant functions generated from the covariant matrices (Table 3). Seven of the soil mapping units and two of the land use classes were accurately differentiated (100%). The communal grazing land use class was the only class that was differentiated at an accuracy of less than 66 percent (Table 3). The commission error, which is a measure of the incorrect assignment of an observation, was fairly high which may imply that the variables used in the discriminant functions did not account for enough of the variability in differentiating the classes or that the classes were too similar in their spectral reflectance and surface soil physical properties. The overall classification accuracy in differentiating among the soil mapping units and land use classes was 88.2% and 67.6%, respectively. These results indicate that the TM DN values and surface soil physical properties can be effectively used to differentiate soil mapping units and major land use classes in Botswana's Southern District.

The results of the multivariate analysis used in differentiating among the soil mapping units and land use classes are given in Table 4.

The variables which accounted for most of the variability in differentiating both the soil mapping units and land use classes were soil structure, erosion intensity, grazing intensity, soil color and texture. Soil compaction and TM bands 4 and 2 were also key variables in differentiating the soil mapping units. However, the amount of variability that these variables accounted for in differentiating the soil mapping units and land use classes was quite low according to the average squared canonical correlation (ASCC) values of 0.3570 and 0.3811, respectively. The ASCC values, however, were significant at the 0.0001 probability level. Wilks Lambda which is a measure of how well the groups are separated was also significant at the .0001 probability level.

The importance of being able to differentiate among surface soil types and land use classes using remotely sensed data is in its ability to evaluate large areas not easily accessible under normal conditions. Botswana is a large country that is sparsely populated with approximately two-thirds of its population living in the eastern third of the country. Because of this, one could encounter areas within the country that are somewhat desolate of people and facilities. Such is the case for parts of the Kalahari Desert and the western portion of this study area. Even though the spectral sensors can only penetrate the upper surface of the soil, they do provide valuable information about the surface conditions which can be useful in mapping and monitoring desolate areas.

Prediction of Surface Soil Conditions

Estimation of surface soil conditions from TM spectral data and soil physical properties for use in soil and land use mapping is an important potential application of remote sensing in Botswana and other countries. Table 5 shows the results of a stepwise regression analysis for selection of the best combination of variables for predicting selected surface soil conditions. Five to six variables were required to generate an equation that would adequately predict the surface soil condition of interest. By computing all of the possible linear regression equations and considering the amount of variability explained and the bias of the resulting equation, the best subset of variables was selected (Table 6).

Soil compaction was best described using TM bands 2 and 4, soil structure, texture, and erosion intensity. The resulting equation explained 36.7% of the variability with a coefficient of variability (C.V.) of 21.37%. Soil crusting was best described using TM bands 2, 3, and 4, soil texture and erosion intensity. However, the equation only accounted for 19.9% of the variability. This suggests that there are probably other variables not used in this study that would better describe soil crusting. The equation was significant, however, at the .01 probability level and unbiased according to the Cp value of 4.28. An unbiased equation (based on the data entered) is indicated by a Cp value that is equal to or less than the number of terms in the resulting regression equation (Mallows, 1973).

Grazing intensity was best described using TM bands 4 and 3, soil structure, erosion intensity, and vegetation percentage. The resulting equation accounted for 76.9% of the variability with a C.V. of 16.62% and Cp value of 3.92. Vegetation percentage was best described using TM bands 3 and 4, soil structure, texture, and erosion intensity. The resulting equation accounted for only 24.7% of the variability and had a high C.V. value of 93.89%. The normalized distance vegetation index (NDVI) was best described using TM bands 2, 3, and 4, soil color, texture, and erosion intensity. The resulting regression equation accounted for 81.2% of the variability with a C.V. value of 13.29%.

These results confirm that the prediction of surface soil conditions such as compaction, crusting, and grazing intensity, using selected TM spectral bands and surface soil physical properties is possible based on the significant R^2 values and low C.V. values that resulted from the data set (Table 6). The results given in Tables 5 and 6 show the contribution of each of the variables that form the relationships. The contribution of TM3 and TM4 in explaining variability in the NDVI relationship was expected; however, the significant contribution of color, texture, and erosion was not. The NDVI index is supposed to be a predictor of biomass or green vegetative cover; however, in this study the percent vegetation cover variable did not significantly contribute to the NDVI relationship. Further, the variables that contributed the most to the relationship for predicting the precentage of vegetation cover were soil structure,

texture, and erosion. The spectral bands, TM3 and TM4, made only minor contributions to predicting vegetation cover. These results concur with other studies conducted in the semi-arid areas of Botswana, the Sahel, and Australia, which reported that NDVI was a poor indicator of vegetation cover (Ringrose and Matheson, 1991a; 1992; Matheson and Ringrose, 1994a; 1994b; Ringrose et al., 1994). These equations are geographically dependent and may not be applicable to other areas. However, equations such as these can be quickly generated for other areas if the TM data is available and the soils' physical properties are known. The prediction of surface soil conditions, such as the ones discussed in this paper, can have an enormous impact on the management practices used to control the wildlife population and grazing of domestic cattle in Botswana's Southern District as well as other parts of the country. The overgrazing problems in Botswana are well documented in many internal publications. It is our hope that the results of this study will be used to help initiate a monitoring program to better manage the country's natural resources.

SUMMARY AND CONCLUSIONS

Discriminant classification of soil mapping units and land use classes based on selected TM spectral bands and surface soil physical properties is possible according to the results presented. Although the amount of variability that the variables accounted for in the analyses was low, the resulting discriminant functions and equations presented were found to be significant based on all the statistical tests used. Highly significant relationships among the spectral data, soil physical properties and surface soil conditions were obtained. Soil mapping units were differentiated at an overall accuracy of 88.6% while the land use classes were differentiated at an accuracy of 66.7%. Prediction of surface soil conditions such as compaction and grazing intensity, and NDVI from the spectral data and surface soil physical properties was highly significant as shown by the high R^2 values. Soil compaction was best described using TM bands 2 and 4, soil structure, texture, and erosion intensity. Grazing intensity was best described using TM bands 3 and 4, soil structure, erosion intensity and vegetation percentage. NDVI was best described using TM bands 2, 3 and 4, soil color, texture, and erosion intensity. Further study of the coding technique used to convert the soil physical properties into numerical values for use in the analysis is encouraged as well as the investigation of other soil variables to better define and describe the relationships presented.

ACKNOWLEDGMENTS

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LIST OF FIGURES

Figure 1. Land use map of Botswana's Southern District showing location of sampling sites. [Reproduced from original map prepared by Environmental Consultants, P.O. Box 10072, Gaborone, Botswana. *In* Southern District Planning Study (1988), N. D. Hunter (ed.)].

Figure 2. Soil mapping units of Botswana's Southern District.

Figure 1.
Landuse Map of Botswana's Southern District Showing Location of Sampling Sites

[Reproduced from original map prepared by Environmental Consultants, P.O. Box 10072, Gaborone, Botswana. In Southern District Planning Study (1988), N.D. Hunter (ed.)]

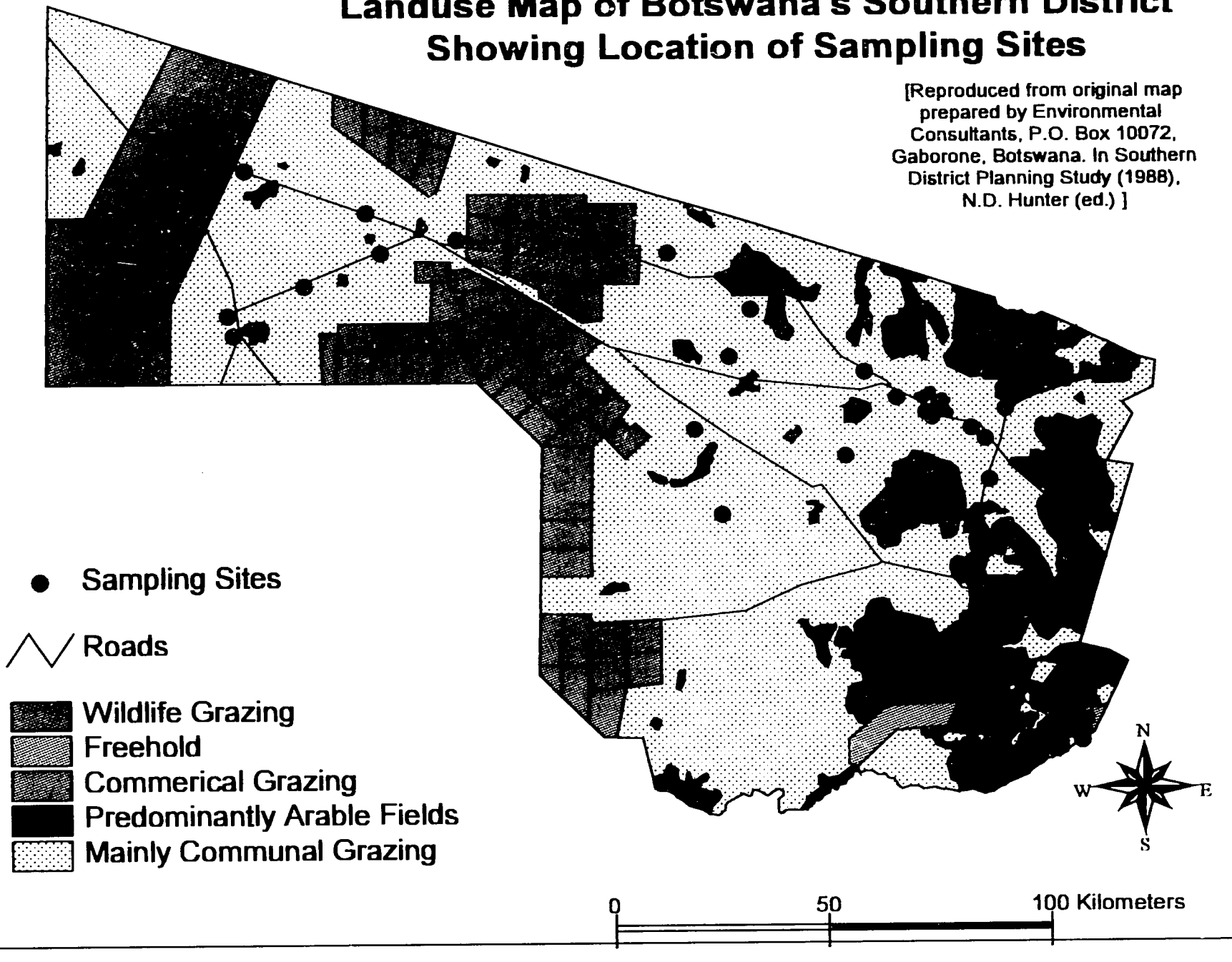
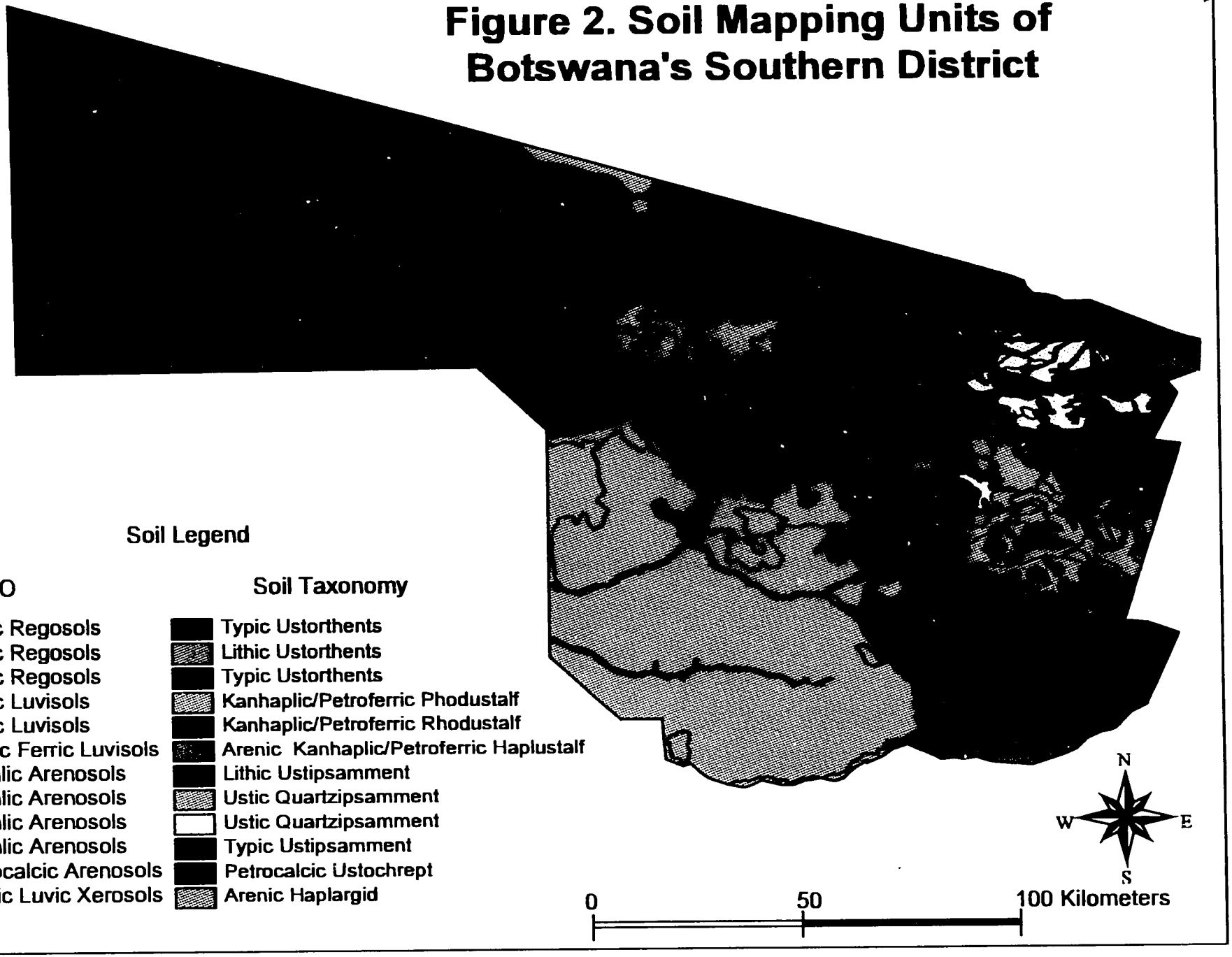


Figure 2. Soil Mapping Units of Botswana's Southern District



Appendix B

Progress Report and Abstract

Spectral and Spatial Dimensions of Rural Land Use Systems in the Southern District of Botswana" is attached in .

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MEMORANDUM

Date: December 5, 1995

To: T.L. Coleman

From: M. Duane Nellis
Charles Bussing

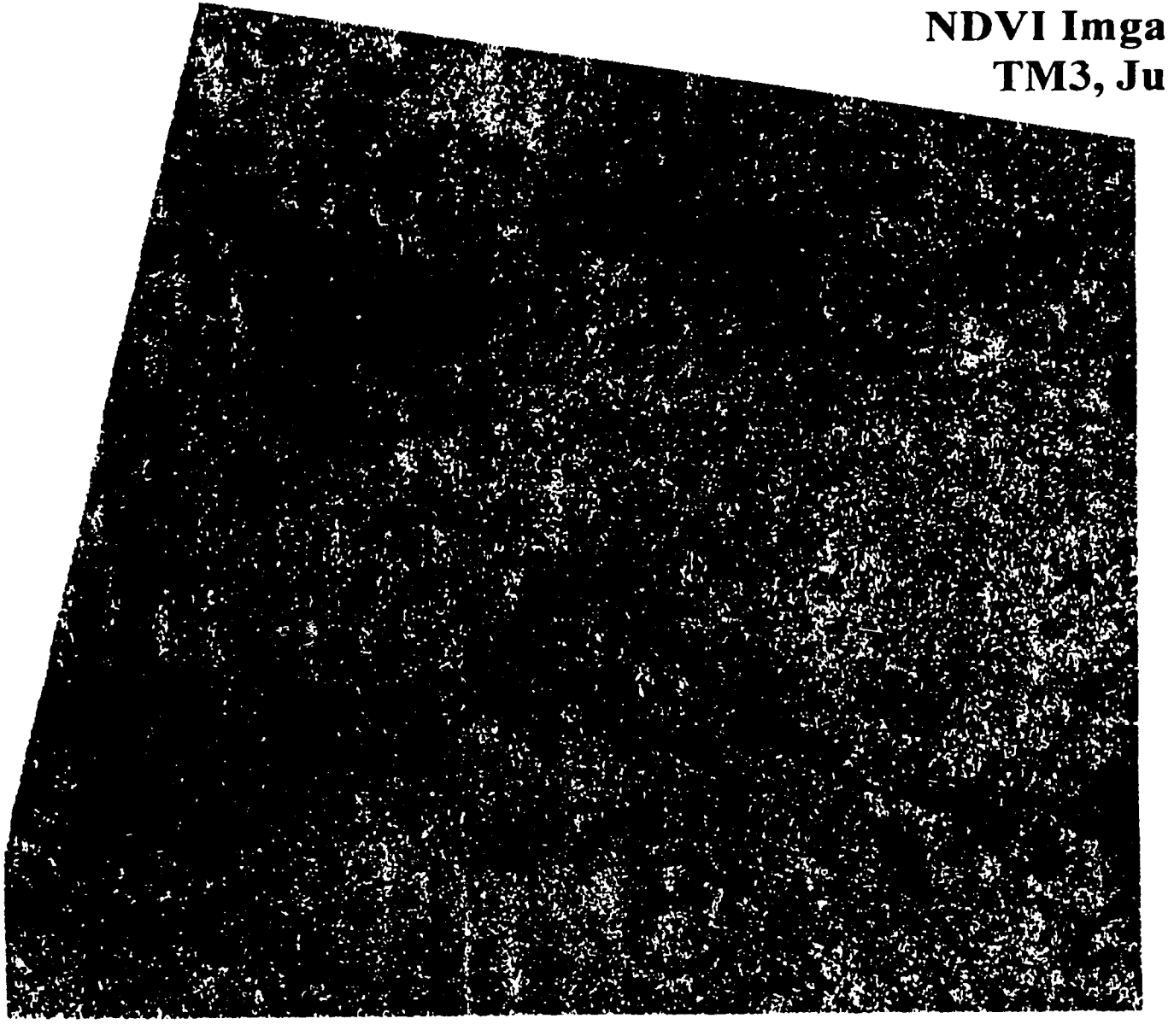
Re: Progress Report--USAID Botswana Project

We are continuing to analyze two dimensions (as our part of the project) of the field data and related satellite data of Botswana's Southern District. These include: (1) an overview analysis of the rural land use system in the Southern District of Botswana, and (2) a multi-temporal analysis manuscript of linkages between grazing intensity indices and Landsat thematic mapper and multispectral digital data sets. Regarding the first of these themes, Dr. Bussing has continued to collect background reference material and initiated writing portions of the manuscript. Relative to the second of these research themes, Dr. Nellis has been working in an attempt to georectify and enhance the original 1994 thematic mapper and 1984 multispectral satellite data sets. Various enhancement algorithms linked to vegetation condition (see attached figure) and impact of grazing intensity are being investigated relative to the 1994 field data. Co-registering the 1994 global positioning system locations and the associated field level attributes with the satellite data has been time consuming, but promises to provide significant results for modeling spatial-temporal dimensions of the rural land use systems. Results of this work will be presented at the Association of American Geographers meeting in Charlotte, North Carolina in April 1996. The abstract has been accepted for presentation (see attached).

M. Duane Nellis and Charles E. Bussing, Department of Geography, Kansas State University, Manhattan, KS 66506-1005, T. Coleman, Department of Plant and Soil Science, Alabama A&M University, Normal, AL 35762, M. Nkambwe and S. Ringrose, Department of Environmental Science, University of Botswana, Gaborone, Botswana. **Spectral and Spatial Dimensions of Rural Land Use Systems in the Southern District of Botswana.**

Few countries depend more on natural vegetation resources to sustain the livelihood of a largely rural population than Botswana. The use of land for livestock grazing is crucial to the economic sustainability this semi-arid/arid country. Range-fed beef is also important as an export item and thus significant source of foreign exchange. Although strategies for development of a sustainable rural land use system have focused on opening up new areas for grazing through provision of water points, increased grazing pressure in all grazing areas has resulted in significant environmental degradation. The development of a National Conservation Strategy, has provided a policy framework to address rural land use issues. The ability to monitor policy effectiveness is limited by a lack of timely resource information on the relationship between rural lands carrying capacity and cattle stocking rates. In this study, Landsat thematic mapper (TM) digital data of Southern District, Botswana was used to analyze variations of grazing intensity. Southern District represents an area of transition between the hardveld of eastern Botswana and the of the Kalahari. Thirty-four sites representing communal grazing, mixed farming, private-commercial grazing, and wildlife management zones were analyzed at ground level land georectified to Landsat TM grazing indices using global positioning system (GPS) precision readings. A stepwise regression analysis of selected land cover variables in relation to the Landsat TM data found that land use degradation was best described using TM bands 4 and 3 in combination with selected land parameters. Results support the viability of using Landsat TM data for multi-temporal analysis of longer-term grazing sustainability.

Keywords: Botswana, rural landuse, remote sensing



NDVI Imgae of Botswana
TM3, July 18, 1994

- Highest value

- Lowest value