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Suitability Model for Land Development and Irrigation Potential in Northeastern Brazil

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ABSTRACT: The present study was conducted from remotely sensed data and GIS technology for mapping of economically irrigable land, which requires a detailed understanding of the ecology, soils, topography, geology and geomorphology of the study area. Under this study a variety of supervised classification methods has been applied and tested extensively for land use planning, management, land development and irrigation potential on two test sites in two different states (Paraiba and Piaui) of northeastern Brazil. The Present study describes some outlines on using these technologies to derive various natural resources and environmental information, such as, land use/land cover classification, soil associations, land capability, slope classes and finally a Suitability Model for land development and irrigation potential for the study area. The result showed a very good performance by SPOT imagery analysed through digital interpretation using ERDAS Software. After receiving these results, it is necessary for the Federal as well State Agencies to explain to the public and farmers the planned projects for Irrigation, Soil Conservation and Land Development to be executed in NE Brazil for its agricultural and economic development, land evaluation and land reforms programs (REFORMA AGRARIAS) of the Federal Government of Brazil.

Keywords: Northeastern Brazil, Land Development, Irrigation Potential, SPOT Imagery, ERDAS Software, Supervised Classification, Digital Interpretation.

INTRODUCTION

Brazil is one of the largest countries of the world and ranks high in terms of its natural resources; yet they have not been documented fully. Northeastern Brazil is primarily semi-arid and is largely undeveloped or underdeveloped. It is characterized by periodic, and often lengthy droughts which have caused economic and social disasters.

The low rainfall and high temperatures coupled with soil problems make it difficult for agricultural, economic, social and industrial development. To address these problems will require a sophisticated and effective land use plan using up-to-date knowledge and technology.

Such development requires a detailed understanding of the natural resources management. The advent of remote sensing and GIS technologies has introduced a new dimension into understanding the northeastern Brazil.

Remote sensing has been approved as a very important and advanced tool for the inventory and analysis of natural resources for regional and local planning at both the small and large scales in more effective management and utilization and for land development and irrigation potential of semi-arid regions of Brazil. But demands for more effective management of northeastern of Brazil´s natural resources will not be met unless arrangements are made to collect pertinent information and to share data in to nation´s interest.

There were selected two test sites for this study: one in the state of Piaui and other in the state pf Paraíba of NE Brazil. The main remote sensing image processing system used for this study is ERDAS-the Earth Resources Data Analysis system. Data from the French environmental satellite, SPOT, were used to detect and delineate surface, erosion pattern and drainage patterns of major rivers and their tributaries, 4 resources layers, such as, land use and land cover; soil associations, land capability classes, and slope classes in the study area of both the states. By-recoding. These layers, in a logical model, a land suitability map for land development and irrigation potential was produced for the two sites of two different states of NE Brazil.

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STUDY AREA

The study area falls in the states of Piaui and Paraiba, which is mainly semi-arid. It has various geological formations, such as halocene, pre-cambrian (B), pre-cambrian (CD), cretaceous and plutonics (mainly granite etc.). The area has various types of dry lands and altitudes varying from 200 to 900 meters. Various types of physiografical relief features and geomorfological forms such as alluvial plains, cultivated fields, hills, iinselbergs, rock ridges and plain areas are encountered. Crop production in the area is almost dependent on natural rains as very little of the area is irrigated with water of ponds and lakes which is collected during the rainy season. The area is covered by natural pastures, wastelands and xerophytic vegetation. Hydrologically, the area is covered by a network of rivers, many of which are intermittent. Soils derived from recent streams sediments are rich, whereas others are poor to moderate in fertility. The major soil groups of the area are: Entisols, Alfisols, Inceptisols, Ultisols and Lithic Sub-groups of various orders and rock outcrops.

Fig. 1: Study sites northeastern Brazil. 1. in Paraiba state, 2 in Piaui state

Crop production and animal husbandry are the major agricultural and economic activities of the region. The principal crops are maize, beans, cotton and sugarcane; animals are goats, sheep and cows. The study area also has extensive areas of various drought-resistant trees and shrubs; mainly Caatinga hipoxerofila, Caatinga hiperxerofila and xerophytic forests. The Climate of the region is semi-arid and falls into two groups: 1. Tropical hot with severe droughts, 2. Tropical hot with droughts of medium intensity. Besides these two Climatic groups, some parts of the study area have small areas, which are hot and humid. Normally the area has a rainfall of 300 to 600 mm per annum and temperatures from 30 to 40 degrees centigrade in the summer.

BACKGROUND

Remote sensing and GIS are the fundamental tools for the inventory and analysis of natural resources for regional, rural and local planning, management and development at both the small as well as the large scales in undeveloped and developing parts of the world. Various types of remote sensing data, such as, SAR, MSS, TM, ETM, MOMS, AVHRR and SPOT etc. lave been used for earth resources management and development of semi-arid regions by various governmental agencies, institutions, and universities. For example: Hill and Megier (1986) performed a digital classification of the Ardeche region of Southern France using Landsat-TM as part of a region-wide resources inventory being conducted by the French government. Kennard *et al.* (1988) have worked on a GIS system for land use planning and management of semi-arid regions of northeastern Brazil, using digital image processing on Landsat-TM and SPOT data. Neillis *et al.* (1990) used Landsat TM for remote sensing and GIS application for rural land use analysis and found that remote sensing technology, in conjunction with GIS, have served as a valuable approach to the rural resources manager. Ulbricht *et al.* (1992 used the supervised classification for the soil and land use studies for a part of semi-arid regions of Brazil. They used this methodology for some parts of the states of Paraiba, Ceara, and Piaui. Teotia *et al.* (1992) have integrated Remote Sensing and GIS technologies for Land Development and Irrigation Potential in the State of Ceara in NE Brazil. They found that the Suitability Map is very beneficial for agricultural development and irrigation projects in the region. Teotia *et al.* (1996) did a very comprehensive work for land use planning in semi-arid regions of NE Brazil, using SPOT HRV data. Teotia, H.S. (1998) have studied the multi-temporal effects in regional planning over a part of semi-arid regions of Paraíba state of Brazil and found that the digital interpretation of SPOT data of 20 m resolution imagery is more reliable for determining detailed assessment of land use/land cover classes and surface hydrology. According to Junior silva (2000), ERDAS Imagine Software é one of the most valuable tool for manipulation and interpretation of geo-referenced satellite data for the development and management program of NE Brazil. Teotia *et al.* (2001) have studied in the state of Paraiba, Brazil and prepared a Model for Land Information System for agriculture as well as land resources development for the region. Ribeiro G. do N. (2006) studied some remotely sensed data and found that the ERDAS Imagine Software and SPOT data is a good combination for land use and land cover mapping and for the development of Agreste region. He found the 86.6% accuracy in his results.

GEOGRAPHIC AND EARTH RESOURCES INFORMATION AVAILABLE

Data about various components required for this research have been gathered from sources as follows:

Information Source

1. Land use	:	Aerial photographs, Field measurements, and Satellite Data from USA, FRANCE & INPE.
2. Soils	:	Aerial photographs, soil maps & reports.
3. Slope and elevation	:	SUDENE (Federal Government).
4. Drought and Floods Data	:	IBGE (Federal Government).
5. Climatic Data	:	EMBRAPA (Federal Government & University Centers.
6. Geological and Hydrological Data	:	University Centers and State Departments.
7. Slope Classes Data	:	EMBRAPA and Soil Conservation Services.
8. Vegetation and Forest Data	:	IBAMA (Federal Government Organization)
9. Economic Data	:	IBGE, and Banco do Brazil.
10. Irrigation and Drainage Data	:	DNOCS, Water Resources Secretariats.
11. Municipality and State Limits	:	SUDENE, Mayors Offices.

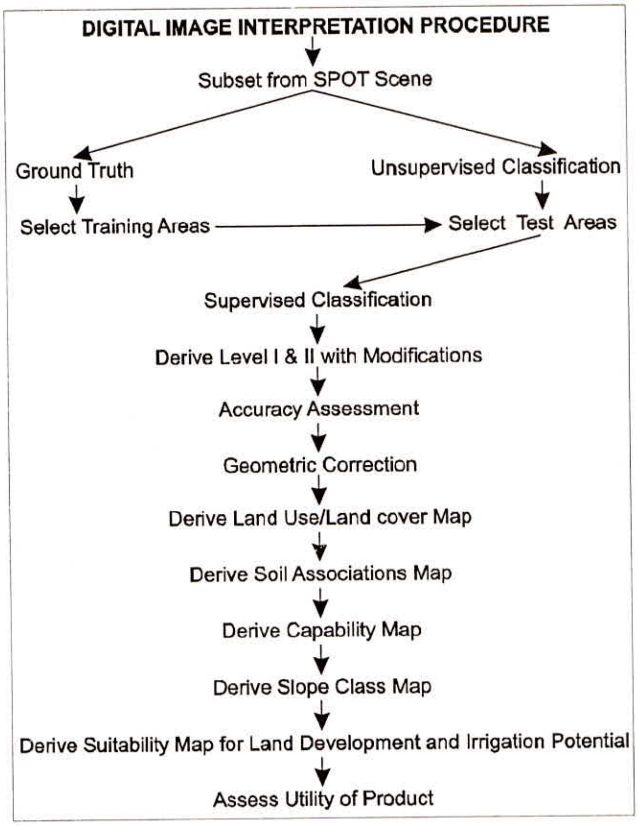
SOFTWARE AND IMAGE PROCESSING

The principal remote sensing image processing system being used is ERDAS-the Earth Resources Data Analysis system. The classification scheme is being modeled after the United States Geological Survey System for use with remote sensing data (Anderson *et al.*, 1976), modified to account for local conditions within the study areas in Brazil.

A 1000 by 1000 pixel sub-scene of SPOT multi-spectral data (band 1, 2, 3) was used for analysis. A hybridized unsupervised-supervised classification approach is being used for the analysis of SPOT data for the classification of land use/land cover classification. More than 80 unique sites (40 in each area) were visited in the study area, and reference data, such as soil, vegetation, geology, topography, climate and others are made to assist in supervised classification. Various field trips served as a basis for accuracy assessment of computer assisted, satellite—derived earth resources maps which were produced during the execution of this study.

Based on the field observations, 30 training areas (in each site) were selected, using the interactive capabilities of an image analysis system for the land use/land cover classes of interest. The relevant statistics were generated for these training areas and a maximum likelihood classification system was applied to the entire 1000 by 1000 pixel image. Finally, 15 and 17 categories at the Level II of land use/land cover classification were selected (Anderson *et al.*, 1976). These Level II classes in both the sites (Paraiba and Piaui) are shown in the modified classification hierarchy given in Tables 2 and 3.

Simultaneous with the selection of training areas for the supervised classification, test area pixels were chosen for each of the categories. These test areas were used to quantify mapping accuracy. The accuracy was assessed by intersecting maximum likelihood classification results with their respective ground truth digital maps. The intersecting of maps revealed the disagreement. The soil associations (USDA, 1975), Land Capability (USDA, 1966 and Brazil, 1983) and slope classes maps (USDA, 1975) were produced by a recoding and correlating of 15 and 17 Land Use/Land Cover classes of Level II. After using various programs of ERDAS Software for recoding and evaluation, four types of earth resources information, such as: (1) land use/land cover, (2) soil associations, (3) land capability classification, and (4) slope classes maps, were derived. The recoding was possible because of the high degree of correlation of land use and land cover with the features of other maps. Field observations conducted at the sites confirmed this relationship. These four earth resources information layers derived from analysis of the SPOT imagery and collateral data were weighted for their relative importance. Finally, these weighted variables were combined in a logical model to generate a suitability classification for land development and irrigation potential. The following flow diagram describes the complete procedure of Digital Image Interpretation of SPOT Data.



Main Model Design (Figure 2)

Under this study various earth resources models are prepared to integrate the results for the development and management of the land. Main models are derived from a set of seven or eight components, each of which is directed towards a specific land management and irrigation potential objective. As an example, the suitability model is derived from several components, such as, geology, topography, soils, hydrology, vegetation, climate (Figure 2). Geological analysis considers the texture, structure and consistency of different parent materials and their resistance to erosion. The topographic landscape sub-model permits analysis of the environmental characteristics of a site in relation to elevation, slope and their direct and indirect relationship to irrigation and development of the land. Soils at the level of subgroups are placed in the correct classification based on their morphological characteristics and their degree of fertility. The natural vegetation sub-model can be used to determine the optimal vegetation species for each area in a site and their capacity to check the erosion. The hydrology sub-model can be used to explain drainage patterns, surface water presence, and the possibility of subsurface water. The land use and land cover sub-model identifies different levels of the land use and land cover classification system considering the climate and site of the study area and their land development.

The main purpose of each model will be to provide sufficient up-to-date information to land use planners at both the regional and state levels. The model may be used for suggesting soil conservation practices such as soil and water management, reclamation procedures and finally land development and irrigation purposes, to know the land is economically irrigable or not. The Model may be designed to be altered according to the site, time requirements and policies of a particular region.

Programs of ERDAS Software used under this investigation

Following programs have been used for unsupervised, supervised classification and Accuracy Assessment.

For Unsupervised Classification:

READ-CLUSTR-DISPLAY-COLORMOD-CLASNAM-RECODE-COLORMOD-CLASNAM-ANNOTAT-CLASOVR-BSTATS-LISTIT

For Supervised Classification:

READ-SEED-SIGDIST-SIGMAN-ELLIPSE-CLASNAM-MAXCLAS-DISPLAY-COLORMOD-CLASNAM-ANNOTAT-CLASOVR-RECODE-INDEX-RECODE-INDEX-COLORMOD-CLASNAM-ANNOTAT-SCAN-BSTATS-LISTIT.

For Accuracy Assessment:

READ-DISPOL-DIGSCRN-GRDPOL-CLASOVR-CLASNAM-SUMMARY.

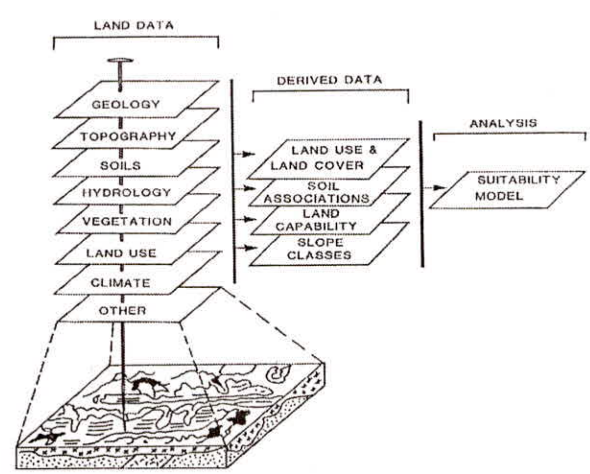


Fig. 2: An example of the use of a Suitability Model for Land Development and Irrigation Potential in Semi-arid Regions of ne Brazil, S.A.

CRITERIA FOR LAND USE AND LAND COVER MAPPING

For our study of semi-arid regions of NE Brazil, the land use and cover classification system (Anderson *et al.*, 1976) is modified in accordance with the local climate, local needs and existing conditions. During the conduct of our project, we will use the following important criteria suggested by the USGS:

1. Interpretation accuracies in the identification of land use and land cover categories from remote sensor data should be 85% or greater.
2. The classification system should be applicable over extensive areas.
3. The categorization should permit vegetation and other types of land cover to be used as indicators of activity.
4. Multiple uses of land should be recognized where possible.
5. The classification system should be suitable for use with remote sensor data obtained at different times of the year and in different years.

In addition, the following criteria suggested by Colomb, Kennard and Civco (1985) and by Civco and Kennard (1983) has also been considered:

1. Individual land use and cover classifications should be customized to facilitate interpretations of digital images with different resolutions.
2. To reduce processing costs and increase accuracy, digital images should be classified and then corrected geometrically.

RESULTS AND DISCUSSIONS (TABLE 1 TO 4 AND FIGURES 3 TO 8)

Comparison of digital interpretation with reference information indicated the digital interpretation closely resembled field observations. A more rigorous, quantitative measure of accuracy performed using the 80 test areas (40 in each site, however, indicated that some categories were classified and more reliably than others. The overall classification accuracy was 84.81% in Piaui (Jaico) area, whereas 85.90% was in Paraiba (Santa Luzia) area. The following tables present a summary for the maximum likelihood classification results of Paraiba SPOT imagery and Piaui SPOT imagery the accuracy is good with respect to the classification categories used for this study. The water, alluvial land, wet and swampy land, eroded and weathered land, saline cultivated depressions and forest classes shown better results than others. Some classes of urban areas, poor drained cultivated, cultivated river bed with dense shrubs and mixed cultivated, shown lower classification accuracy. Mixed cultivated and fallow land showed the lower classification agreement. From these results it is found that the inability to discriminate among certain classes is due to the spectral similarity between these categories. Other spatially-oriented data are required to augment and enhance the classification process (Civco, 1987). The classification shows that the heterogeneous areas also reduce the accuracy percentages of the classifications. The land use/land cover classification units were recoded and various types of maps were produced for both the test sites. 1. Soil association map, 2. Land capability map, 3. Soil class map and finally 4. Suitability map for Land Development and Irrigation Potential. For our study purposes we have shown here only the Land Use/Land Cover Classification and the Suitability results in tabular form as follows:

Table 1: Paraiba (Santa Luzia) Land Use/Land Cover Classification

Mapping Units	*Description*	*Accuracy %*
W1	Deep to very deep water	98.80%
W2	Moderately deep to deep water	100.00%
W3	Very shallow to shallow water	100.00%
U1	Dense urban area	58.70%
U2	Sparse urban and barren rocky land	85.80%
CF1	Cotton cultivated and fallow land	86.32%
MF1	Mixed cultivated and fallow land	59.16%
CP1	Mixed cultivated and Pasture	86.10%
A1	Alluvial land with dense shrubs/trees	82.97%
A2	Alluvial cultivated and eroded	82.20%
F1	Sparse Caatinga forest and rocky land	89.20%
F2	Sparse to moderately Caatinga forest	90.00%
F3	Moderately to dense Caatinga forest	91.78%
F4	Dense Caatinga forest on undulating land	88.52%
F5	Dense Caatinga forest on hills	87.85%
Total Overall Accuracy		85.90%

Table 2: Paraiba (Santa Luzia Region) Suitability Classification for Land Development and Irrigation Potential

Mapping Units	*Description*
1. Water	
2. Urban	
3. Very Poor	Very poor for land development and irrigation potential
4. Poor	Poor for land development and irrigation potential
5. Fair	Fair for land development and irrigation potential
6. Moderately good	Mode good for land development and irrigation potential
7. Good	Good for land development and irrigation potential

Table 3: Piaui (Jaico) Land Use/Land Cover Classification

Mapping Units	*Description*	*Acccuracy %*
W0	Deep water	98,80%
W1	Moderately deep water	100,00%
W2	Shallow silted water	100,00%
W3	Moist area	92,50%
SFA	Swampy flooded area	89,20%
UO	Urban area with barren rocky land	73,80%
EFA	Eroded flooded area	85,00%
PDC	Poor drained cultivated and eroded	72,60%
PDC1	Poor drained cultivated	73,70%
AMC	Alluvial mixed cultivated	84,90%
CRB	Cultivated river bed	84,80%
CRB1	Cultivated river bed with dense shrubs	83,00%
SCD	Saline cultivated depression	72,80%
WERM	Weathered eroded rocky and moist land with Sparse vegetation	83,80%
DCF	Dense Caatinga forest	96,20%
MDCF	Moderately dense Caatinga forest on undulating topography	92,80%
SPC	Sparse Caatinga forest on undulating and Eroded topography with poor cultivation	88,00%
	Total Overall Accuracy	84,81%

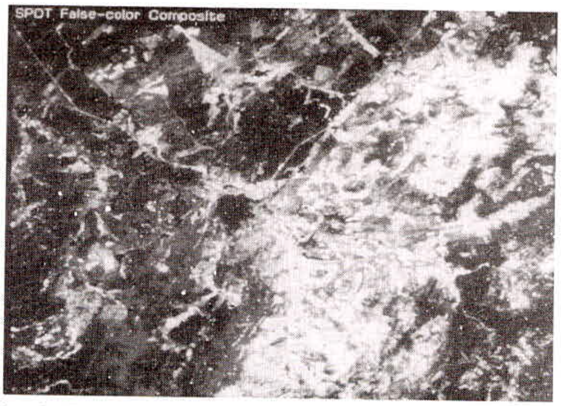


Fig. 3: PARAIBA (SANTA LUZIA) SPOT False-color Composite

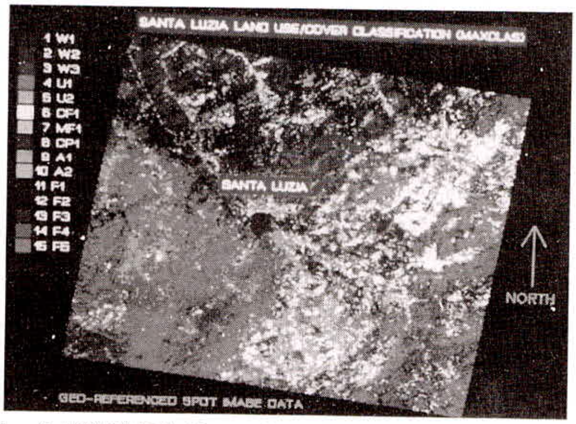


Fig. 4: PARAIBA (Santa Luzia) Land Use/Land Cover

Table 4: Piaui (Jaico) Suitability Classification for Land Development and Irrigation Potential

Mapping Units	*Description*
1.	Water
2.	Poor for Land Development and Irrigation Potential
3.	Fair for Land Development and Irrigation Potential
4.	Good for Land Development and Irrigation Potential
5.	Very good for Land Development and irrigation Potential

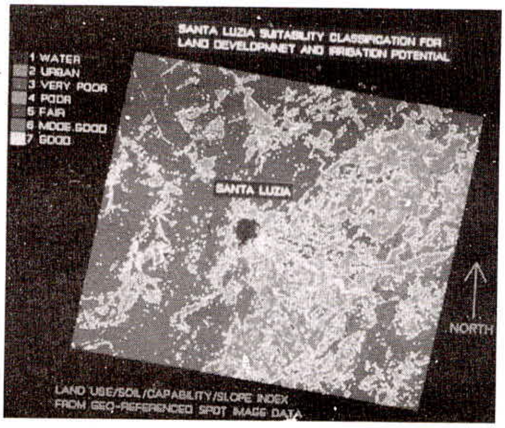


Fig. 5: PARAIBA (Santa Luzia)

Fig. 6: PIAUI (Jaico)

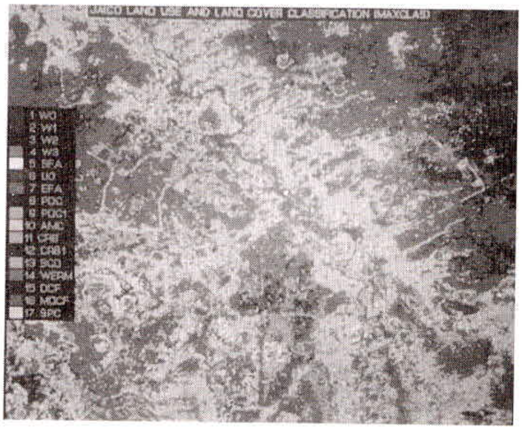


Fig. 7: PIAUI (Jaico)

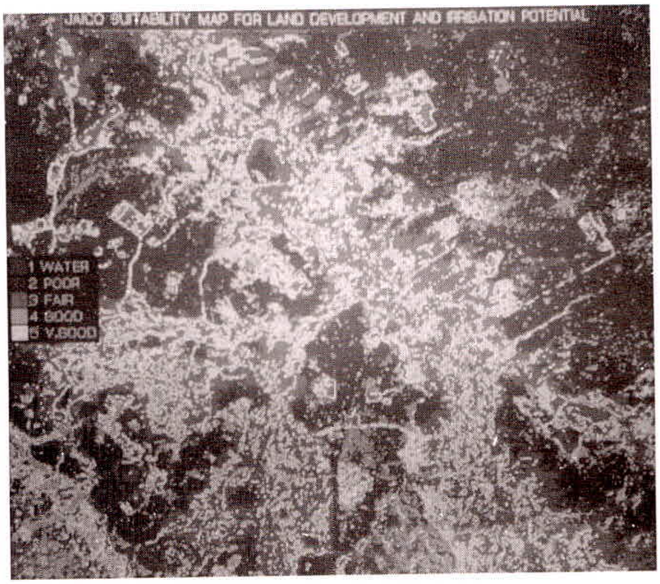


Fig. 8: PIAUI (Jaico)

GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. Digital interpretation of SPOT imagery with 30 m and 20 m resolution proved to be effective to determining detailed assessment of land use and land cover classes, soils, Slope classes and surface hydrology for selected areas in the semi-arid regions of NE Brazil.
2. The combination of unsupervised and supervised classification of SPOT data for Land Use/Land Cover mapping and accuracy assessment provided satisfactory results. In terms of operational reliability, the per pixel maximum likelihood classification of SPOT image data offered the most satisfactory results in comparison to other classification systems. Th get more information about the Land Use and Land Cover classes the multitemporal images from different seasons are necessary.
3. Suitability map for land development and irrigation potential will be very beneficial for agricultural development, soil conservation management, irrigation projects in the area. Also this type study is urgently needed for the Land Reform Program (PROGRAMA DE REFORMA AGRARIAS) of the Federal Government of Brazil.

REFERENCES

Anderson, J.R., Hardy, E.E., Reach, J.T. and Witmer, R.E. (1976). "A land use and land cover classification system for use with remote sensing data. U.S. Geological survey." Reston, VA (USA), *Profesional Paper* 964, 28 pp., illus.

ERDAS 7.5 (1991). Field Guide.

Hill, J. and Megier (1986). "Rural land use inventory and mapping in the Ardeche area using multitemporal TM data." *Intl. Geosci. And Remote Sensing Symp. Zurich (Switzerland),* 2: 1135–1141.

Kennard, W.C., Teotia, H.S. and Civco, D.L. (1988). "The Role of an Automated GIS in the Development and Management of Renewable Natural Resources of northeastern Brazil." In: *Proc. Of 16th Int. Cong. Of Photogrammetry and Remote Sensing (ISPRS), Kyoto (Japan),* pp. (B9; 220–231.

Neillis, M. Duane, Lulla, K. and John Jenson (1990), "Interfacing Geographic Information system and Remote Sensing Rural Land Use Analysis" In: Photogrammetric Engineering and Remote Sensing (ASPRS). Falls church, Virginia (USA), pp. 329–331.

Ribeiro, G.do N. (2006), Mapeamento do Uso da Terra e Cobertura Vegetal em Área do Agreste Paraibano, utilizando Técnicas de Sensoriamento Remoto e Geoprocessamento, Areia: UFPB, pp 93 (Dissertação de Mestrado).

Silva Junior, E.B. (2000). Avaliação multitemporal da atividade antrópica na região de Santa Luzia-PB com o uso de Geoprocessamento, Areia: UFPB, pp. 66 (M.S. Thesis).

Teotia, H.S. and Ulbricht, K.A. (1992). The Integration of Remote Sensing and GIS Technologies for Land Development and Irrigation Potential in the State of Cerara, NE Brazil. In: ISPRS-General Convention, Washington, D.C. August 2–14 Intl. Arch. Photogrammetry and Remote Sensing xXIX, Comm. VII, pp. 466–472.

Teotia, H.S., Santos, J.R. dos, and Ulbricht, K.A. (1998). "Multitemporal Effects in Regional Planning over a part of Semi-Arid Regions of Paraíba, Brazil." In: *Internal symposium on "GIS-Between Visions and Applications"*, ISPRS, Stuttgart, Germany, pp. 19–30.

Teotia, H.S., Costa Filho, J.F., Santos, J.R. and Ferreira, L.A. (2001), Integração do Sensoriamento e SIG na preparação de modelo de desenvolvimento da terra para planejamento rural. In: Simpósio Brasileiro de Sensoriamento Remoto, 10., Foz de Iguaçu-PR, Brazil. Anais ...São Jose dos Campos-SP: INPE.