THE INTEGRATION OF REMOTE SENSING AND GIS TECHNOLOGIES FOR LAND DEVELOPMENT AND IRRIGATION POTENTIAL IN THE STATE OF CEARA, BRAZIL

Harendra S. Teotia
Federal Univ. of Paraiba (UFPB)
58397-DSER/CCA/UFPB, Areia-PB, Brazil

Klaus A. Ulbricht
DLR-Optoelectronic
8031-Oberpfaffenhofen, Germany

Daniel L. Civco
College of Agriculture
UCONN 06266 Storrs, CT, U.S.A.

COMMISSION VII

1. ABSTRACT

The integration of remotely sensed data and geographical information systems (GIS) for mapping of economically irrigable land requires a detailed understanding of the ecology, soils, topography, and geomorphology of the study area. This paper reveals some outlines on using these technologies to derive various types of maps, such as land use and land cover classification maps, maps of soil associations, maps of land capability classification, maps of soil slope classes, and finally a suitability map for land development and irrigation potential. It is necessary for the state and federal agencies and institutions to explain to the public and farmers the planned projects for irrigation, soil conversation and land development to be executed in northeastern Brazil for its agricultural and economic development.

2. INTRODUCTION

Northeastern Brazil is primarily semi-arid, is largely undeveloped or underdeveloped, and is characterized by periodic, and often lengthy, drought which has caused economic and social disasters. Northeastern Brazil is composed of nine states, one of which is Ceara. Oros in Ceara is the biggest water reservoir of northeastern Brazil. The water of this reservoir can be utilized to raise the crop production of the region. Before utilizing this water for irrigation we must know if the land is economically irrigable or not. Proper development of the region requires a detailed understanding of the natural resources, such a minerals, soils, ecology, vegetation, and water.

Remote sensing deals with the detection and analysis of earth surface features and phenomena using imagery acquired from aircraft and satellites. Geographical information systems (GIS) are systems for management and display of information to be used in a decisionmaking framework. Operational applications of GIS today include activities such as land and resources management, traffic planning, marketing, military planning, and a wide variety of other uses.

This paper describes a remote sensing and spatial data analysis system for the development and management of earth resources data in the state of Ceara, Brazil, aiming at the land development and irrigation potential in the semi-arid regions.

3. BACKGROUND DISCUSSIONS

Nowadays, remote sensing and geographical information systems (GIS) are important and advanced tools for the inventory and analysis of renewable natural resources. The demands for effective management and utilization of Brazil's natural resources will not be met without the sharing of data in our nations's interest.

Various types of remote sensing data from satellite, such as MSS, TM, SPOT and AVHRR have been used with GIS for natural resources management and development of semi-arid regions of the world. For example: Kennard et al (1988) 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. Johnson (1989) developed a digital map based on a Hydrologic modeling system (MAPHYD) and applied it to the urban watershed studies. Zhou (1989) developed a relational image-based GIS (RIGIS) for interfacing geographic information system and remotely sensed data for land resources studies in the arid zone of Australia.

Everitt et al. (1989) explained that multispectral Video imagery can be used successfully to differentiate among various soil surface conditions. These techniques are useful for irrigation management. Steyaert (1989) explained that current GIS technology and cartographic data represent major untapped resources to meet crossdisciplinary research needs of nontraditional GIS users involved with global change research.

Lyle and Stutz (1989) described systematic methods using GIS and remote sensing for rural land planning which formed the bases for land use planning for the areas of southern California. Smith and Blackwell developed an image based information system (IBIS) program, which allowed cross correlation of Landsat imagery and topographic data with a variety of environmental data relating to such parameters as surface runoff, drainage basin acreage, and terrain configuration. Lo et al. (1990) used GIS technology for the study of changes in land use for the development of new cities. They concluded that this technology may contribute to various types of research, such as management of satellite data, research about natural resources, management and land use planning for irrigation and thematic mapping and environmental control. Neillis et al. (1990) used the Landsat-TM for remote sensing and GIS application for rural land use analysis and found that remote sensing technology, in conjunction with GIS, has served as a valuable approach to the rural resources manager.

Teotia et al. (1990) have used the SPOT HRV for land use/land cover and soil/land classification in the state of Piaui in Northeastern Brazil and found it an inexpensive means of mapping natural resources over a large areas. Hui et al. (1991) used remote sensing techniques combined with ecological and geological information to produce a series of systematic maps for a part of China.

4. PROCEDURE

4.1 Study area

The study area of this investigation is mainly semi-arid and situated at a distance of about 400 km from the city of Fortaleza, capital of the state of Ceara. The study area lies between, 39° 03′ W to 39°25′ W longitude and 6°02 S′ to 6°22′ S latitude. It has various types of physiological relief and geomorphical forms such as alluvial plains, low land, cultivated fields, hills, rocky and eroded land. Crop production in the area is dependent principally on natural rains as some areas are irrigated with water collected in lakes and ponds during the rainy season. At some places the area is also covered by natural pastures and waste lands.

The area is productive and has good types of soils, such as Vertisols, Alfisols, Inceptisols and Lithic subgroups, but because of unavailability of sufficient funding for its development as well as inadequate planning, has lagged in its full development compared to many other parts of northeastern Brazil.

4.2 Collection of Earth Resources Information

Data about the components which are necessary for this study are gathered from various sources as follows:(s.table 1)

All information is being evaluated for completeness and accuracy. As well, additional Computer Compatible Tapes of Landsat-TM are acquired so as to provide temporal as well as spatial coverage of the study areas.

4.3 Software and Processing of Data

The principal remote sensing image processing system used for our study is ERDAS (Earth Resources Digital Analysis System), using a 80386-based super-micro-computer with image display system.

A 1000 by 1000 pixel subscene of Landsat-TM multispectral data (band 3, 4, and 5) was used for analysis. A hybridized unsupervised-supervised classification approach is used for the analysis of Landsat-TM data for the classification of land use/land cover classification. More that 44 unique sites were visited in the study area, and reference data, such as soil, vegetation, geology, topography, climate and others were made to assist in supervised classification. Various field trips served as a basis for accuracy assessment of the Computer-assisted, satellite -derived earth resources maps which were produced during the execution of this study.

Based on the field observations, 27 training areas were selected, using the interactive capabilities of an image analysis system for the land cover classes of interest. The relevant statistics were generated for these training areas and a maximum likelihood classification was applied to the entire 1000 by 1000 pixel image. Finally, 12 categories at the Level II of land use/cover classification were selected (Anderson et al., 1976). These level II classes are shown in the modified classification hierarchy given in table 2.

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 the maximum likelihood classification results with their respective ground truth digital maps. This intersecting of maps revealed the precategory amount of agreement and disagreement. The soil associations (USDA, 1975), land capability (USDA, 1966, Brazil, 1983) and slope classes maps (USDA, 1975) were produced by a recoding of and correlating of the final 12 land use and land cover classes of Level II. Six soil associations, six land capability units, and 5 soil slope classes were identified. In each classification the class one was designated by water. In fact, there were 5 soil associations, 5 capability units and 4 soil slope classes. The major units and their characteristics of each map are shown in table 3, 4, and 5.

Geometric correction was applied only after all operations were performed. Eleven control points and the corresponding topographic map received from SUDENE (1972) at the scale of 1 : 100.000 were selected. The x and y coordinates from the image were recorded for each of the 11 points. The

Table 1: Earth Resources Information

Major information	Sources
1. Geology	Satellite data, field survey and existing maps.
2. Soils	Existing soil maps of small scale, field survey, technical reports, satellite data.
3. Land use/cover	Existing maps and reports, Satellite data and field survey.
4. Topography (slope and evaluation)	Topographic maps from SUDENE, field survey
5. Forest and vegetation	IBAMA, existing maps, and field survey
6. Climate (precipitation, temperature, humidity)	EMBRAPA, UFCE, existed maps and reports
7. Municipality and state limits	Administrative units of the cities and states, and SUDENE.

Table 2: Ceara land Use/Land Cover Classification

No.	Symbols	Description	Pixels	%
1.	W1	Deep to very deep water	29.340	2.93
2.	W2	Mod. deep to depp water	15.606	1.56
3.	W3	Shallow silted water	17.568	1.76
4.	W4	Shallow and polluted water	2.770	0.28
5.	U5	Urban areas with rock outcrops	16.885	1.69
6.	C1	Cultivated nearly level land	106.569	10.66
7.	C2	Sparse to mod. cultivated undulating land	207.654	20.77
8.	A1	Alluvial mod. to dense cultivated land	113.948	11.39
9.	A2	Alluvial mod. cultivated and eroded undulating land	107.670	10.77
10.	F1	Dense caatinga mixed forest on hills	7.090	0.71
11.	F2	Mod. dense caatinga forest on undulating topography	57.421	5.74
12.	F3	Sparse caatinga forest on eroded shallow and undulating land	317.479	31.75
	Total:		1.000.0	100.00

image positions of these coordinates were interactively identified and an affine transformation matrix was calculated (RMSE 1 pixel). None of the control points was rejected. Finally, the five types of earth resources information listed previously were derived from the geometrically corrected image. The first four maps were prepared by recoding the digital land use and land cover classification. The recoding was possible because of the high degree of correlation of land use and land cover with the features of other maps. Field investigations conducted at the sites confirmed this relationship. The first four earth resources information layers derived from analysis of the Landsat-TM 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. (Figure 1). Accuracy was assessed by intersecting the maximum likelihood classification results with their respective ground truth digital map which revealed the per-category agreement and disagreement.

Environmental satellites such as Landsat-TM have been used effectively for our objectives. Not only can maps be made, but also the means to update them are at hand. Complex analysis of the interaction of many factors can be carried out simultaneously. This methodology involves a coordination of both the image processing activity itself as well as maintenance of the derived information with the geographic data base management sub-system.

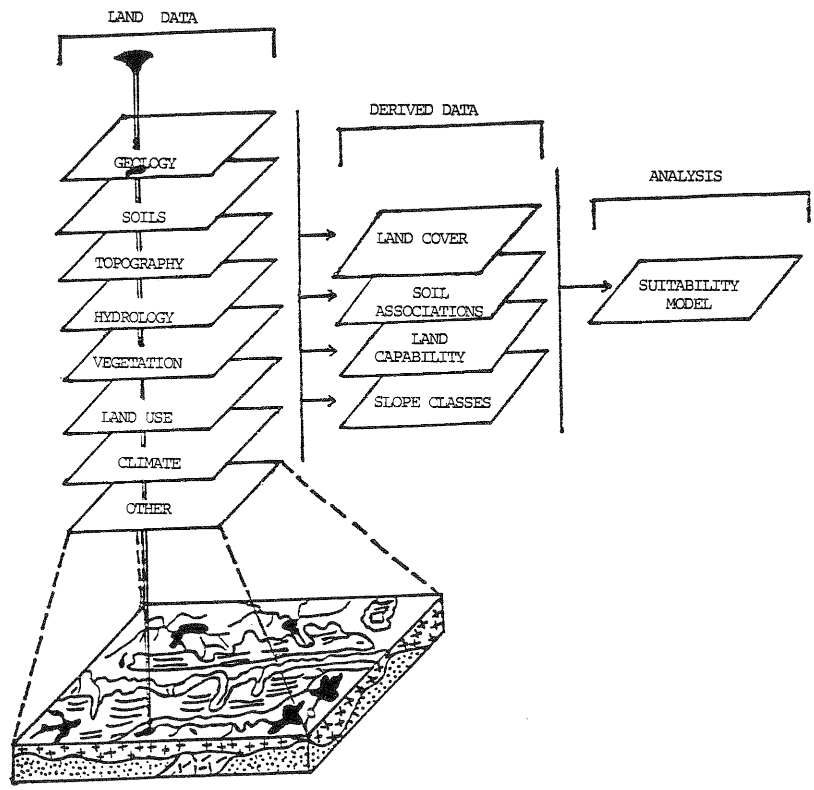

Figure 1: AN EXAMPLE OF THE USE OF A SUITABILITY MODEL FOR LAND DEVELOPMENT AND IRRIGATION POTENTIAL IN THE CEARA STATE OF NE BRAZIL

4.4 Main Model Designs

Under this study, various earth resource 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: geology, topography, soils, hydrology, vegetation, climage (Figure1). Geologic analysis considers the texture and structure and consistency of the different parent materials and their resistance to erosion. The topographic landscape submodel 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 submodel can be used to determine the optimal vegetation species for each area in a site and their capacity to check the erosion. The hydrology submodel can be used to explain drainage patterns, surface water presence, and the possibility of subsurface water. The land use and land cover submodel identifies different levels of the land use and land cover classification system considering the climate and site of the study area and their in land development. The principal 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 models may be used for suggesting soil conversation 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. Models are designed to be altered according to the site, time requirements and policies of a particular region.

5. RESULTS AND DISCUSSIONS

A more rigorous, quantitative measure of accuracy performed using the test area, indicated that some categories were classified and mapped more reliably than others. The accuracy of the extracted features relative to the original map data was higher than the preliminary results of this investigation. The overall classification accuracy was 81.3 %, satisfactory with respect to the classification categories used for this study. The overall classification accuracy, however, is often not a good indicator of reliability because it accounts for pixels

Table 3: Ceara Soil Associations

No.	Mapping Units	Pixels used	%	Explanation
1.	Water	65.284	6.53	LSGR=Lithic Sub-Groups
2.	Urban/Barren	16.885	1.69	RO=Rock Outcrops
3.	V(HU)-FA-CU	314.223	31.42	UP=Ustipsamments
4.	UF-UP-UO	221.618	22.16	UO=Ustorthents
5.	LSGR-RO-UO	64.511	6.45	HU=Haplustalfs
6.	LSGR-HU(V)-RO	317.479	31.75	UF=Ustifluvents
				V =Vertisols
Total:		1.000.000	100.00	

Table 4: Ceara Land Capability

No.	Mapping units	Pixels used	%	Explanation
1.	Water	65.284	6.53	
2.	Urban/Barren	16.885	1.69	
Moderately good land for cultivation:				
3.	IIIs	314.223	31.42	Soil problems
4.	IIIes	221.618	22.16	Erosion and soil problems
Relatively good land for cultivation + Marginal land for cultivation:				
5.	IVes/VIs	317.479	31.75	Erosion and soil problems
Land not suited for cultivation:				
6.	VIIes	64.511	6.45	Erosion and soil problems Land good for pasture and afforestation
Total:		1.000.000	100.00	

Table 5: Ceara Slope class name:

No.	Mapping units	Pixels used	%	Explanation
1.	Water	65.284	6.53	
2.	Urban/Barren	16.885	1.69	
3.	1-5 %	535.881	53.58	Under A-C Classes
4.	5-15 %	317.479	31.75	Under C-E Classes
5.	15 % and more	64.511	6.45	Higher than E Classes
Total:		1.000.000	100.00	

Table 6: Ceara Suitability Classification for Land Development and irrigation potential

No.	Mapping units	Pixels used	%	Explanation
1.	Water	65.284	6.53	
2.	Very Poor	64.511	6.45	V.Poor for Irrigation
3.	Poor	16.885	1.69	Poor for Irrigation
4.	Fair	317.479	31.75	Fair for Irrigation
5.	Good	535.841	53.58	Good for Irrigation
Total:		1.000.000	100.00	

that are correctly classified and not measure commissions (false inclusions of pixels) that were omitted from correct classification into other categories. Brennan et al. (1989) explained that to accurately evaluate the reliability of this type of investigation (disregarding human intervention errors) individual classes should be inspected for agreement with the ground truth data and the extent of the commissions evaluated.

Deep to very deep water (W1); moderately deep to deep water (W2); shallow silted water (W3); urban areas with rock outcrops (U1); cultivated nearly level land (C1); alluvial moderately to dense cultivated land (A1); dense caatinga mixed forest on hills (F1); and moderately dense caatinga forest on undulating topography (F2) classes have shown the better results in terms of high percentage agreement with ground truth data (76-100 %) and relatively low percent commissions (0.09-15.8 %). These results show that the digital data of these classes are spectrally homogeneous and easily discriminated from other classes of the region. The other classes such as shallow and polluted water (W4); sparse to moderately cultivated undulating land (C2); alluvial moderately cultivated and eroded land (A2) and sparse caatinga forest on eroded shallow and unbdulating land (F3) are more spectrally heterogeneous and explain the lower overall classification accuracy (53.83 to 71.82 %) and high commission percentage (23.80 to 47.72 %).

It is concluded that the inability to discriminate among certain classes is due to the spectral similarity between categories, and is a problem with pattern recognition (Maximum likelihood classification) method dealing with per pixel spectral data alone. Other spatially-oriented data are required to augment and enhance the classification process (Civco, 1987). The classification shows that the percentage accuracy is decreased as the level of detail is increased. The more spectrally heterogeneous areas also reduce the accuracy percentage of the classification. The following tables 3, 4, 5, and 6 give the characteristics of the soil associations, land capability, slope class names and suitability map for land development and irrigation potential, derived from the original 44 categories of the digital land use and land cover map using RECODE and INDEX programs of ERDAS system.

6. GENERAL CONCLUSIONS

1. Digital interpretation of Landsat-TM of 30 m resolution imagery proved to be effective in determining detailed assessment of land use classes, soils and surface hydrology.

2. Classification became less accurate as the level of detail was increased. The relatively low accuracies of some categories at the Level II were attributed to cross-confusion among the related categories.

3. Accuracy assessment of the digital classifications showed that some categories such as water, forest and alluvial land were identified more accurately than other categories.

4. In terms of operational reliability, the per pixel maximum likelihood classification of Landsat-TM image data offers the most satisfactory results. The reliable acceptable categories may be used as a framework for the addition of residual classes through a more conventionalapproach (Photointer-pretation).

5. Maps of soil associations, capability classification and slope class names prepared using the RECODE program and other information may be used for detailed planning and development and management of the region.

6. The suitability map for land development and irrigation potential will be very beneficial for agricultural development, soil conservation management and irrigation projects in the region.

7. LITERATURE CITED

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

2. Civco, D.L.1987. Knowledgebased classification of Landsat-Thematic Mapper digital imagery. Ph.D. Dissertation. The University of Connecticut, Storrs, CT, (USA), pp. 214.

3. Everitt, J.H., Escobar, D.E., Alaniz, M.A. and M.R. Devis. 1989. Using Multi-spectral Video Imagery for detecting soil surface conditions. In: Photogrammetric Engineering and Remote Sensing (ASPRS), Falls Church, Virginia (USA), pp. 467-471.

4. Hui, A.H., Yan, G.H., Yun, H.T. and Yang Ming Jun. 1991. Study on the Application of Remote Sensing Techniques in Systematic mapping of Natural Resources and Environment. Proc. of 24th International Symposium on Remote Sensing of Environment (ERIM), Rio de Janeiro (Brazil).

5. Johnson, L.E. 1989. MAPHYD- A Digital Map-Based Hydrologic Modeling System. In: Photogrammetric Engineering and Remote Sensing (ASPRS), Falls Church, Virginia (USA). pp. 911-917.

6. Kennard, W.C., H.S. Teotia, and Daniel L. Civco. 1988. The Role of an Automated GIS in the Development and Management of Renewable Natural Resources of Northeastern Brazil. Proc. of 16th Int. Cong. of Photogrammetry and Remote Sensing (ISPRS), Kyoto (Japan). pp. (B9): 220-231.

7. Lo, C.P., and Robert L. Shipman. 1990. A GIS Approach to Land use change dynamics detection. In: Photogrammetric Engineering and Remote Sensing (ASPRS). Falls Church, Virginia (USA), pp. 1483-1491.

8. Lyle john and Frederick P. Stutz. 1989. Computerized Land use Suitability Mapping. In: Photogrammetric Engineering and Remote Sensing (ASPRS), Falls Church, Virginia (USA), pp. 66-76.

9. 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). 329-331.

10 Smith, A.Y. and Richard J. Blackwell. 1989. Development of an information Data Base for watershed Monitoring. In: Photogrammetric Engineering and Remote Sensing (ASPRS), Falls Church, Virginia (USA), pp. 154-165.

11 Steyaert, L.T. 1989. Investigation the use of geographical information systems technology in the computer workstation environment for global change research, Technical papers. 1989 ASPRS/ACSM Annual Convention, Baltimore, Maryland (USA), 4:46-57

12 SUDENE. 1973. Levantamento exploratorio-reconhecimento de solos do Estado do Ceara, Boletim Tecnico No. 28. Serie Pedologica No. 16, Recife, Pernambuco (Brazil). pp. 502.

13 Teotia, H.S., Ulbricht, K.A., Civco, D.L. and W.C. Kennard. 1991. Utilization of SPOT data for land use/cover mapping and soil/land classification in the Piaui state of northeastern Brazil. XXIV ERIM Conference, Rio de Janeiro (Brazil). pp......

14 USDA. 1966. Land Capability Classification, Soil Conservation Service, Agriculture Handbook No. 210, Washington, DC (USA).

15 USDA, 1975. Soil Taxonomy-A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Soil Survey Staff. U.S.Soil Conservation Service, Agriculture Handbook No. 436. Washington, DC (USA), pp. 764.

16 Zhou Qiming. 1989. A Method for Inegrating Remote Sensing and Geographic Information System. In: photogrammetric Engineering and Remote Sensing (ASPRS), Falls Church, Virginia (USA), pp. 591-596.