LANDSAT MONITORING OF TEMPORAL HIDROLOGICAL VARIATIONS AND ACTUAL LAND USE ON THE LAGUNA YEMA AREA (FORMOSA PROVINCE, ARGENTINA)

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ABSTRACT

Digitally processed multi-temporal Landsat data has increased the value of Landsat's temporal characteristics for many resource management applications. In the present study, the nature and impacts of changes in hydrological features and the actual land use of a selected site within the area, are analyzed from three Landsat-Geopic images acquired in 1980, 1981 and 1982.

The study focuses on a 30.000 Km2 area in the central portion of the Province of Formosa in northeastern Argentina. The area is located within two major basins: that of the Rio Bermejo and of the Rio Pilcomayo.

Since Laguna Yema is a multi-million dollar project thought to provide drinkable and irrigation water to the majority of Formosa Province, the importance of this study is obvious.

1. INTRODUCTION

The Province of Formosa is between approximately 22.5 and 27 south latitude and 57,5 and 62,5 west longitude. The capital of the Province, Formosa City, is located in the easternmost part of the Province. The northern border of the Province is also the international boundary between Argentina and Paraguay. The Province is boarded in the south by the Bermejo River, dividing Formosa and Chaco (Argentina) Provinces.

Laguna Yema is located approximately 375 Km west of the capital city of Formosa. It can be reached using ground transportation by proceeding west from Formosa city along highway route 81 to the town of Laguna Yema, then south on route 37 Km for 15 Km to the Laguna Yema.

The Landsat analysis covers an area of approximately 30.000 square kilometers, extending from the Rio Bermejo to the Rio Pilcomayo ,covering a large portion of central Formosa Province.

Surficial hydrology conditions periodically impact, and constrain, economic development and land manangement over many areas of Formosa Province. Due to physiographic features exhibiting minimal topographical relief characteristics, temporal innundations often cover extended land areas following local precipitation periods as well as from waters transported into the Province in the extended Rio Pilcomayo and Rio Bermejo watersheds. The situation in Formosa Province is similary present over adjacent Provinces, e.g., Chaco Province, lying within the Gran Chaco physiographic region.

Landsat earth resource satellite images have been analyzed in several projects to investigate and map natural resources in Formosa Province, including surficial hydrology and temporal hydrological dynamics. For example: in 1977, Aeroterra S.A. prepared "Estudio de los Recursos Naturales de la Provincia de Formosa", including detailed maps for land use, vegetation, hydrology, geology and geomorphology, at 1:250.000 scale, based on Landsat image interpretations, and complemented with Skylab 3 photograps. In 1981, Aeroterra and Earthsat analyzed digital Landsat-Geopic images to map the distribution and ecological characteristics of Vinal (Prosopis ruscifolia) in a study area located in Patino and Pirane Departments in Formosa Province. Also in 1981, Aeroterra and Earthsat conducted studies of the Rio Pilcomayo-Banado La Estrella zone, based on temporal Landsat-Geopic processed imagery.

These studies further described in their respective reports, have domonstrated the value of timely, regional, remote sensing data and analyses to the planning, development and management of hydrological, vegetation and other resources in Formosa Province. The present study extends the information provided in the Laguna Yema region of the Province, using techniques and procedures previously demonstrated to be effective and useful in providing data to provincial planners, land and water managers, and decision-makers.

2. OBJECTIVES

The principal objective of this project was to study the temporal hydrological changes in the Laguna Yema region of Formosa Province using Landsat temporal data for three time periods in 1980 (September 22), 1981 (March 21) and 1982 (January 3). This objective involved a series of tasks including processing of the Landsat imagery, computer analysis of surficial water, and synthesis of the analysis results.

3. STUDY AREA

The ground hydrological features of the Laguna Yema project area have been described and mapped by Aeroterra S.A. (1977, Estudio de los Recursos Naturales de la Provincia de Formosa; Mapa Hidrologico). The study area lies both the Rio Pilcomayo and Rio Bermejo drainage areas, with the divide located approximately 3 kilometers north of the Laguna Yema. The dominant direction of drainage, following regional slope, is from west/northwest to east/southeast. The A. Trenquito provides ephemeral drainage into the Laguna Yema. Overflow from Laguna Yema follows an alluvial plain southeastward towards the town of Las Lomitas.

Throughout the study area, several "canadas", ancient, sediment-filled channels, serpentive in outline which resemble rivers of sand coursing through the expanses of xerophilous vegetation which blanket the older surfaces of the Gran Chaco region. Some areas contain depressions deep enough to hold water during wetter periods which drains through percolation and/or evaporates. Residuals of moist soils may apperar on Landsat images. Water flow and ponding in the "canadas" follow and outline subtle variations in relief which are in many instances imperceptible to an observer in the field. The differential distribution of water during the rainy season still reflects the original landscape and enhances the inherited subtle relief, causing formation of bands of soil with different moisture content and pedologic development. These variations, in turn, control the relative vigor and even species of plants which grow on these features. In earlier studies of the Pilcomayo-Banado La Estrella region, adjacent and overlapping the Laguna Yema project area, field observations suggested that gross variations in vegetation apperar to be more closely related to the yearly range in near surface moisture content than to the texture and age of soils.

The Gran Chaco Region is situated in a humid subtropical mesothermal forest climate which is constantly moist and which may receive rainfall all through the year (after Koppen as modified by Trewartha). The climate in the project area is an important environmental characteristic, particularly precipitation which is highly variable both in frequency and intensity. This variability strongly impacts the management of the region natural resources. Further, this variability increases westward in character with the climate of the Gran Chaco Region.

Although the average total annual precipitation in the project area is slightly less than one metre, it is evident that averages are of rather limited value when data are examined over a number of years. In addition, evaporation rates are high, exceeding precipitation throughout the Chaco Region, resulting in an annual net deficit water budget in a region which experiences excessive water during portions of the year. The general pattern, however, in the Laguna Yema study area, is for a dry winter (July is the driest month) and a wet summer with a rainy period extending into early fall (March is the wettest month)

4. SELECTION AND PREPARATION OF LANDSAT DATA

Three Landsat scenes were selected and acquired in Computer Compatible Tape (CCT) fromat from CNIE (Argentina receiving station). These scenes were digitally processed to produce Geopic images. Geopic images are digitally processed color composites of Landsat scenes of superior quality, containing substantially more information than is available from other sources.

Standard Geopic processing was applied to each of the Laguna Yema Landsat scenes, resulting in enhanced color composite photographic prints containing bands 4 (green), 5 (red) and 7 (reflective-infrared), displayed as blue, green and red, respectively. The three Landsat scenes for WRS Path 245/Row 077 selected and acquired for this project are: 1) Images No. 22450-77114, 22 september 1980; 2) Image No. 22450-77124, 21 March 1981; 3) Image No. 22450-77140, 3 January 1982.

In all three Landsat scenes processed, a linear contrast stretch was applied to the pixel data. The linear stretch shifts the lowest and highest values of the original distribution to histogram values to represent extreme black and white tones. The remaining pixels are distributed linearly, with a 0.7 weightive factor, between the two extremes. The result is that gray level or tonal distribution are increased, resulting in more scene contrast throughout the images. Subsequent to computer processing, the images are converted from digital format, on magnetic computer tapes, to photographic film from which products are generated for analysis and distribution.

Following production of the Geopic images, preliminary visual analyses were conducted to refine computer processing procedures and to analyze hidrological characteristics and features on each image.

5. EVALUATION AND INTEGRATION OF METEOROLOGICAL DATA

Differences in surficial water coverage over various flood-prone zones within the Laguna Yema project area are readily apparent from visual analysis of the three Landsat Geopic images acquired in September 1980, March 1981 and January 1982. Comparison of these images show areas which have drained from previous innundation, areas which are temporarily innundated, often by very shallow water depths; areas of forest coverage with water innundation under the forest canopy; areas of saturated soils which are residual to previous periods of standing water, etc., resulting in part from a characteristically poorly drained landscape. In order to better understand landscape and environmental conditions extant for each Landsat image date, examinations and analyses of meteorological records for selected time periods preceeding the Landsat images were conducted.

6. DIGITAL REGISTRATION OF THE TEMPORAL CHANGE IMAGES

The three Landsat images used for the Laguna Yema temporal change analysis were first processed through the Geopic image enhancement system to correct for the systematic and geometric distortions evident in the Landsat area.

For temporal change analyses, Landsat scenes must undergo further correction so that overlapping ground areas common to all temporal scenes will precisely register to each other. In the present study, the three scenes were digitally registered to each other. Using the September 22, 1980 Landsat-Geopic image as the governing scene, the March 21, 1981 and January 3, 1982 Landsat-Geopic images were the rectified to overlay the September 22, 1980 Landsat-Geopic image

Geometric Control and Transformation using a linear interpolation algorithm were employed for each of the spectral bands of all three Landsat-Geopic images to obtain precise scene to scene registration.

7. IMAGE CLASSIFICATION OF HIDROLOGICAL FEATURES

The Geopic Interact system was used to classify surface water on each of the three registered Landsat images. The classification approach consisted of using a density slice of Landsat MSS band 7 to discriminate the majority of surface water in the image. This technique easily separated deep, clear water bodies, but shallow or extremely turbid water tended to be confused with other spectral signatures. To correct this situation a four band parallelpiped classification was used to discriminate shallow or turbid water as a separate class. The parallelpiped classification is equivalent to performing a density slice operation on each of the four bands and taking the logical intersection of the results. A pixel must fall within the density slice range in each of the four bands in order to be included in the class. The turbid water class was combined with the band 7 density slice class to yield a single calss of surface water for each image.

Landsat-Geopic images of the three image dates were used to select training areas. At least five 512 pixel by 512 line (30 x 30 Km) training windows were selected for each date. Training windows for each date included the area surrounding the Laguna Yema, the section of the Rio Bermejo just south of the Laguna Yema and a section of the Banado La Estrella /Rio Pilcomayo area. Other training windows were selected according to the particular surface hidrological features of each date. The general classification procedure for each date was:

1) Select initial MSS band 7 density slice limit from the Laguna Yema training windows,
2) Check density slice on Rio Bermejo window, and adjust if necessary.
3) Train on Rio Bermejo to define parallelpiped limits of turbid water class,
4) Test classification parameters (both density slice and parallelpiped) on the Banado La Estrella/Rio Pilcomayo area and other training windows. Adjust if necessary.
5) After final adjustments, recheck all windows,
6) Classify entire area and tabulate results.

8. RESULTS OF THE TEMPORAL CHANGE ANALYSES

To complete the Landsat analyses of temporal hydrological changes, the classified surface hidrology features of each of the three Landsat images were recordes on black-and-white photographic film. In addition the areas of overlap in surface hidrology features between the 1980 and 1981, 1980 and 1982, 1981 and 1982, and 1980, 1981 and 1982 Landsat images were discretely recorded on film.

Two separate temporal change analyses were prepared: The first analyses is for temporal changes in all three Landsat-Geopic image dates (1980-1981-1982); the second analyses is for temporal changes in only two of these images, 1981 (the wettest image) and 1982 (the driest image). Each of the temporal surface hydrology features were assigned discrete colors by the computer system, and combined with MSS band 5 of the 22 September 1980 Landsat image which provided spatial orientation to the displayed data.

The results of both analyses were presented in both cartographic (scales 1:100.000 and 1:250.000) format and in statistical form. The statistical results are bases on the number of pixels assigned to each category (color) and converted to hectares (each resampled pixel is 57 m by 57 m, or 0.3249 hectares).

In the three date temporal change analysis the entire image area is the land area common to all three digitally registered Landsat-Geopic images, defined as 2829 rows by 2574 columns totalling 7,281,846 pixels which convert to 2,365,871,7 hectares. The total amount of area covered by water on one or more image dates totals 47,935.1 hectares, which represents approximately 2.0 percent of the total image area. The tabular results are summarized in Table 1.

TABLE 1. Three-date temporal change results

Category	Color	Pixels	Hectares
a-Water in 1980	Green	5896	1,915.6
b-Water in 1981	Blue	96344	31,302.2
c-Water in 1982	Magenta	9387	3,049.8
d-Water in 1980-1981	Orange	7068	2,296.4
e-Water in 1980-1982	Yellow	724	235.2
f-Water in 1981-1982	Dark Green	20043	6,512.0
g-Water in 1980-1981-1982	Red	8076	2,624.0
TOTAL		147,538	151,102.8

In order to analyze surface water for any given year, several categories must be combined. For example, all surface water in 1980 includes Green, Orange, Yellow and Red on displayed image. All surface water in 1981 includes Blue, Orange, Dark Green and Red, and in 1982 includes Magenta, Yellow, Dark Green and Red.

Total 1980 water (a+d+e+g) = 7,071,1 hectares
Total 1981 water (b+d+f+g) = 42,734.6 hectares
Total 1982 water (c+e+f+g) = 12,421 hectares

In the two date temporal change analyses the entire image contains 7,281,846 pixels equivalent to 2,365,871.7 hectares. The total amount of area covered by water on both image dates totals 46,019.6 wich represents approximately 1.9 percent of the total image area. The tabular results are summarized in Table 2.

TABLE 2. Two-Date Temporal Change Results

Category	Color	Pixels	Hectares
a-Water in 1981	Blue	103,412	33,598.6
b-Water in 1982	Green	10,111	3,285.1
c-Water in 1981-1982	Red	28,119	9,135.9

In order to analyze surface water in either individual year, the year color must be combined with the two year color. For example all surface water in 1981 is represented by Blue and Red; all surface water in 1982 is represented by Green and Red.

Total water in 1981 (a+c) = 42,734.5 hectares.
Total water in 1982 (b+c) = 12,420,9 hectares.

9. LAND-COVER CLASSIFICATION

As an additional part of the project a supervised/non-supervised land-cover classification was made in an area of 850 square kilometers extracted from the 22 September 1980 Landsat scene. This classification was performed experimentally in order to explore the possibility of doing similar studies in other bigger areas of the province.

In order to meet the proposed objective, collateral data such as maps and ground-truths of other previous studies were correlated with that of the Landsat image.

An interactive combination of supervised and non-supervised classifcation techniques was used. In this way, with the available ground data and the Landsat image, it was possible to identify the different spectral signatures for the various land-cover minimum of non-classified pixels. A non-grouped, non-supervised euclidean distance algorithm was used in order to make the initial grouping ot hte pixles within the training areas.

Two training areas of 37 by 76 pixels, were extracted for each of the classes. At the same time, the Landsat image was being observed in order to interactively identify areas with unique spectral signatures. In this way different reflectance vectors were extracted. These vectors were used as initial seed of the grouping program of euclidean distance, to be developed later. The program started separating, around each seed, the pixels with the minimum euclidean distance as compared to that of the initial seed.

In this way, 7 land-cover classes were defined, and the results presented in both cartographic (image) format and statistical form. The classes were the following:

Category	Color	Hectares	%
Water	Blue	426	0.5
Urban/Bare Soil	Cyan	8,349	9.8
Veg with high IR reflectance	Red	4,261	5.0
Grasses	Dark Red	4,686	5.5
Riverine vegetation	Green	51,969	61.0
Mixed high/low Forest	Brown	14,568	17.1
Without clasifying	Black	937	1.1

10. CONCLUSIONS AND RECOMMENDATIONS

The Laguna Yema project focused on an area in central Formosa Province where periodic water innundations impact development and economic activities. The present study has analyzed Landsat earth resource satellite images for three dates acquired over an approximately 15 month period to quantitativelu document and map the spatial distribution of surface water at various levels of innundation. The project succesfully met its objectives.

The Laguna Yema study applied previously demonstrated applications of temporal Landsat data to the synoptic analysis of the Laguna Yema study area in a timely and cost effective manner.

An important objective of the present study was to examine multi-date Landsat imagery and apply Geopic system techniques to the analysis of temporal changes of surface hidrology features. An analysis of multi-date Landsat data is useful for identifying the surface hidrological features of the project area, and their spatial distribution. The Landsat images are also useful for identifying upland hidrological features such as abandonned channels and canadas, and associated water flow and ponding which are often related to subtle variations in relief and which are frequently imperceptible to an observer in the field.

A map was produced at 1:100.000 and 1:250.000 scales showing surface hidrological features observed on the Landsat images for both three-date and two-date change analyses. Each year is shown in a unique color overprinted on a black-and-white Landsat-Geopic image (1980).

The maps and accompanying statistical data may appear to understate the extend of flooding to readers of this paper. This is common, due to the perceptions of ground-based observations. For example, the ground based observerer, standing at the edge of an extensively innundated area, perceives water over vast expanses, perhaps as far as he can see, which may be several kilometers. But from the ground, or even from low flying aircraft, the total area within ones vision is restricted to no more than a few hundred square kilometers.

The satellite, however, from an altitude of over 900 kilometers, images in a single scene, an area of over 30,000 square kilometers. The area common to all three scenes in the Laguna Yema study was approximately 23,658 sq. km., much of which was south of the Rio Bermejo and therefore in Chaco Province. On the March 21, 1981 Landsat scene, over 34,000 hectares were classified as water. This is a considerable amount of surface water, even though it is only a small percentage of the total imaged area.

The land use map covers an area of approximately 29 km x 29 km, centered on the Laguna Yema, and contains seven generalized categories. These categories represent land cover and can generally be related to ecological environments, incorporated soils, lanform and clinmate variations over the mapped landscape.

The land use map was not specified in the objectives and products of the Laguna Yema project, but it was included to demonstrate a cost effective approach to developing generalized land use maops for the entire province. Such maps, at a reconaissance level of detail and 1:500.000 map scale, provide valuable planning data. When analyzed with the Geopic images and the two-date temporal change, maps of surface hydrology, analysts can better identify specific zones and areas for more detailed studies of potential hydrological engineering projects. In essence, the analyses provide the basis for planning evaluations of engineering design.

Effective planning and design in Formosa Province must consider the physiographic and vegetative landscape over which present hydrologic and morphological processes operate. Features built by sedimentation of the Rio Pilcomayo and Rio Bermejo over the past two to three million years dominate the landscape. Ill-planned alterations of man, as simple, for example, as a road with inadequate drainage channels resulting in an impoundment which is quickly innundated over many hectares, can resulkt in ecological impacts which may be undesirable and require decades to reverse. With carefull planning and design, the harmony between man and nature can exist anywhere.

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