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AUTOMATIC INTERPRETATION OF MSS-LANDSAT DATA APPLIED TO
COAL REFUSE SITE STUDIES IN SOUTHERN
SANTA CATARINA STATE, BRAZIL*

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ABSTRACT

The coal mining district from southeastern Santa Catarina State is considered one of the most polluted areas of Brazil. This study presents the preliminary results on the application of MSS-LANDSAT digital data to monitor the coal refuse areas and its environmental consequences in this region.

1. INTRODUCTION

The utilization of MSS-LANDSAT data to monitor the coal-mining and reclamation activities has got a strong impetus in the U.S.A., during the last decennium, partly due to a detailed and severe environmental legislation; the Surface Mining Control and Reclamation Act.

Since then a great amount of information has been gathered on the use of digitized LANDSAT data to inventory areas affected by coal mining (e.g. Alexander et alii,(1975); Hughes et alii,(1975); Wobber et alii (1975); Fish (1977); Russell (1977); Anderson & Tanner (1978); Mamula (1978); Bayne & Lawrence (1979)). Besides that, a great effort has been done on studies over coal mining areas using multi-channel airborne scanners, thus permitting a better understanding of the spectral characteristics of the targets to be mapped with satellite data (e.g. Spisz (1978); Tanner (1979); Spisz & Dooley (1980) and Irons et alii (1980)).

In the coal mining areas from south Brazil (States of Santa Catarina and Rio Grande do Sul) systematic studies to monitor the mining activities and the collateral environmental degradation, using MSS-LANDSAT data, have not yet been undertaken. Within this perspective the "Projeto Carvão", which is being developed at INPE. aims to adapt and to apply remote sensing techniques to studies on the environmental problems derived from the mining activities at the Southern Santa Catarina Coal Basin and adjoining areas. Taking into account that the pyrite-rich coal refuses which cover a large terrain extension in this region, can be considered as the main pollution sources in this area, the objective of this study is to map the coal refuse sites in the two most affected areas. The first one (Fig. 1) is part of the elder mining area, encompassing the cities of Criciúma (110.660 inhabitants, *1980), Cocal (6500 inh., 1980) and Siderópolis (12.400 inh., 1980). The second one, located between the cities of Tubarão (75.500 inh., 1980) and Laguna (39.600 inh., 1980), at the lower section of the rio Tubarão, is a coastal plain where a lagoonal-estuarine ecossystem is being severely damaged by the very acid drainage running down from refuses and slurries, pertaining to a nearby installed coal-washing
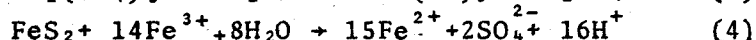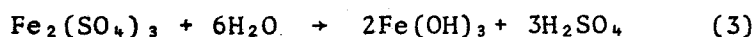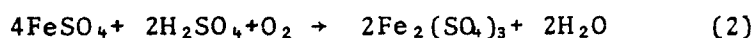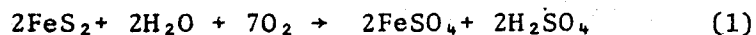
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facility and to a thermoelectrical power plant. In the second area it is also tried a first approach to map the visible extent of the pollution effect by the identification of the acid stressed vegetation along the drainage from the main coal refuse deposit.

2. GEOGRAPHICAL SETTING OF THE POLLUTION PROBLEMS

Both study areas have a high population density, especially the municipality of Criciúma (403 inhab./km², 1980). Within the last 12 years the population from this city grew at a rate of 3% p.a., and it is expected to grow even faster in the coming years, when several heavy industries will be installed in its surroundings. This intense urbanization process is partly due to closing of older, unproductive mines, partly to emigration from rural areas, caused by low productivity of the annual cultures in small farms, hilly terrain, leaching and erosion of soils, etc. Because of severe river pollution, the drinking water supply for Criciúma comes from the foothills of the "Serra Geral", by pipeline, some 60 km to the west of the city. Water shortages are already frequent during the dry season (from May to August). After Cardoso et alii (1981), a total amount of 110.000 m³/day of liquid spills with pH values between 2 and 3, with sulphate contents of 7000 miligrams/liter and iron contents of 2000 miligrams/liter are expelled from the mines and coke ovens. Together with the liquid spills an intensive leaching of the fine materials (silts and clays) occurs at the refuse piles, causing siltation problems in the rivers draining the mining area.

Due to a high content of impurities, such as ashes, the coal from the Southern Santa Catarina Coal Basin has to pass through a long beneficiation process, which can be summarized as follows (Lenz, 1977): the material coming out of the mine, the so-called "run of mine" (ROM), passes through a preliminary washing procedure, and is divided, by density, in two fractions. The first comprehends a variable volume of pyrite-bearing refuses (with up to 20% of pyrite) and losses, corresponding to 70% of the total ROM volume. The second, with an average ash content of 28%, called "pre-washed coal"(PWC), is transported by railroad to the Central Coal Washing Unit at Capivari, near the city of Tubarão. After crushing and washing it is separated in two equivalent portions; the first consisting of metallurgic coal (with 18,5% ashes and 1,8% sulphur), and the second of boiler coal (with 40% ashes and around 3% sulphur), which is burned at a nearby located thermo electrical power plant. The values cited are averages valid for the best betuminous coal seam in S. Catarina; locally the figures for refuses, ashes and sulphur can be higher. Part of the pyrite-rich refuses originated during the beneficiation process, (250.000 tons/ year of pyrite residues with 44% S) are used at a sulfuric acid plant, located in the coal harbour of Imbituba (Putzer, 1977).

During the preliminary washing procedure mentioned above, the sulphur contained within the pyrite (FeS_2) undergoes several changes in the presence of water and air (Barton, 1978), namely:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 \qquad (1)$$

$$4FeSO_4 + 2H_2SO_4 + O_2 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O \qquad (2)$$

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4 \qquad (3)$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (4)$$

In equation (1) the sulfate ion is originated by an oxidation of iron disulfide; in equation (2) ferrous iron becomes non-hydrosoluble ferric iron. When the concentration of sulphuric acid decreases in water, ferric iron is hydrolyzed to ferric hydroxide (equation 3), which origins a red-yellowish coloration within the acid rivers. Another reaction of pyrite with water is its oxidation by ferric iron (equation 4). Accordingly to the same author the longer interruption or ceasing of mining activities can increase these acid

producing reactions if the water is no longer drained or pumped. This situation is very often found in the area around Criciúma. Another type of refuse from the coal mining activity, the "sterile spoils", are the overburden material, originated at open pit mines, which prevail around and north of Siderópolis, where the coal beds are localized very close to soil surface. Its polluting potential is much lower than the pyrite-rich spoils, since the latter contribute almost only with fine sediments to silting in the drainage from the area.

The second area under study mentioned, the coastal plain at the lower rio Tubarão, presents several lagoons, conected by narrow channels with the open sea. The prevailing vegetation is an association of low and high marshes, partially drained for rice paddies and pastureland. The coal refuses and slurries from the Coal Washing Unit and thermoelectrical power plant are deposited at one of the upper edges of this ecossystem. The resultant very acid drainage pours into the lagoons destroying a great portion of the fishing grounds for shrimps and fishes. It should be emphasized that the fishing activity is the feeding basis for over 2000 fishermen families living around these lagoons. An undesired consequence of the destruction of the fish grounds has been a massive proliferation of mosquitos, hence impeding cattle--breeding in that area.

Considering the brazilian National Coal Plan (Ramos, 1982) a reliable forecast, it is expected, at 1985, a total annual production of 17 million tons of PWC. The Southern S. Catarina Coal Basin, will certainly participate with at least two-thirds of this amount, namely with around 12 million annual tons of PWC. This production will correspond to at least 24 mil./tons of refuses and slurries with imprevisible consequences for the environment and men.

3. MATERIALS

- Color infrared (C.I.R.) aerial photographs from August, 1978, at the scale of 1:45.000.

- Coal refuse charts compiled by the E.C.P. (Engenheiros Consultores & Projetistas) staff.

- MSS-LANDSAT's CCT, row path annotation 178/32 from April 24, 1978.

- General Electric Company's Multispectral Image Analyser Image-100 (I-100).

4. METHODS

In the following two sections the pre-processing procedure will be briefly described:

4.1 ATMOSPHERIC EFFECTS CORRECTION

In order to minimize the atmospheric effects of backscattering from sun radiation and target reflection of diffuse sky radiation, the following procedures were developed, after a personal communication with R. P. Lyon:

- An area of the edge of the basaltic plateau in Santa Catarina State, where deep valleys occur, therefore featuring extended relief shadows, was enlarged to a scale of 1:100,000 at the display of the I-100.

- Using the "cluster synthetizer" algorithm (General Electric Comp.,1975), those pixels whose channel 7 values ranged from 0 to 1 in a 255 resolution, were alarmed and designated to one of the I-100 themes.

- This theme was used as a sample in a "single-cell parameter extraction" algorithm (General Electric Comp., 1975), and the mean values of these

pixels for each other channel were subtracted from the whole frame.

4.2 RADIOMETRIC CORRECTION

In order to eliminate the striping effects derived from different responses of the MSS-LANDSAT sensors from the same band, a routine procedure based on a local operator was applied to the frame.

The operator compares the local average of a line with the local average of the anterior line and if the difference is greater than a given threshold, this difference is added to the point of the current line. In order to avoid error propagation, another threshold is input to the system, which establishes a limit to be added to each point (Dutra et alii, unpublished).

4.3 GROUND TRUTH ANALYSIS

The ground truth available for the Criciúma area was a series of coal spoil area charts. The following classes from these charts were used in this study:

sterile spoil
{
- active
- abandoned and unvegetated
- abandoned and vegetated

pyrite-rich spoils
{
- active
- abandoned and unvegetated
- abandoned and vegetated

For the Tubarão area, C.I.R. photographs were available. Through visual interpretation, 24 land-use/land cover classes could be identified and were classified into a hierarchical system (Anderson et alii, 1976). The level I from this system is presented below:

I - coal related areas
II - urban areas
III - agricultural areas
IV - wetlands
V - forestlands
VI - barelands
VII - water

4.4 AUTOMATIC ANALYSIS OF MSS-LANDSAT CCT

The first approach to both study areas was an unsupervised classification aiming at the stratification on the areas into spectrally alike classes. This is done by a cluster algorithm, the "Média K" algorithm (Dutra et alii, unpublished).

The cluster algorithm implemented at INPE's I-100 starts counting the number of pixels occupying each cell in a four-channels space. Then it orders these cells decreasingly according to the number of pixels within the cells.

The first k cells will be the k starting centers of the algorithm. It calculates the euclidean distances between these centers and the rest of the cells. With a nearest neighbor routine, it attributes each cell to one of the centers. The mean values of each channel for each population will be the new centers, and the interaction is repeated. A minimum number of cells is given in order to a population be considered as one. This procedure stops when it achieves a given number of interactions or when the distance between the new center and the last one is below a given threshold. The mean vector and the covariance matrix of the populations enter into a "maximum likelihood" algorithm (Velasco et alii, 1979) in order to classify the whole frame.

4.

Considering that the objectives for the two study areas were different, so were the procedures used for each one.

In the Criciúma area, the aim was to identify and to localize only the coal related areas. So these areas were sampled and the pixels obtained were used for the unsupervised classifications with six centers. On the other hand, the objective in the Tubarão area was to identify acid stressed vegetation as well as healthy vegetation and coal related areas. Therefore, to use the entire scene as a sample would be the best procedure. But this cannot be done at INPE's I-100 because of physical restraints of the system. To solve this problem, the resolutions of channels 5 and 7 of MSS-LANDSAT were reduced to 64 levels and the whole scene with only these two channels was input to the unsupervised classification with 8 centers.

Both classifications were not satisfactory. Errors (commissions and omissions) were presented in all classes. The next step was to subdivide the unsupervised classes into specific classes using the C.I.R. aerial photographs or the refuse deposit charts as ground truth, and the unsupervised classification for sample orientation in a supervised procedure,(Lyon & Prelat, 1978).

The 8 classes of the Tubarão area were divided into 18 classes corresponding to most of the level II classes identified in the aerial photographs. The 6 classes of the Criciúma area were reorganized according to the 6 classes found in the coal refuse area charts.

The supervised classification for both areas was based on a "maximum likelihood decision system" algorithm (Velasco et alii, 1979).

The visual impression of the classification of the Tubarão area into 18 classes was much too confusing, with an excessive fragmentation of the scene. The discrimination of the acid stressed vegetation from other land cover classes was not possible.

The study in the Tubarão area then turned to a land use/land cover classification where the following 8 classes were well identified:

- coal related areas
- urban areas
- high marshes
- low marshes
- agricultural areas
- plowed lands
- forestlands
- water

In the Criciúma area, the six coal refuse classes were aggregated into two, and new land use classes were identified. The final classification was fairly good, featuring the following classes:

- pyrite-rich spoil areas
- sterile spoil areas
- urban residential areas
- industrial areas
- water bodies

5. DISCUSSION OF RESULTS

The identification of acid stressed vegetation in the Tubarão area was not feasible, probably because of the date of the satellite overpass (April), just at the end of the wet season in the region. So, both acid stressed marshes and acid stressed pastures were identical to the corresponding healthy vegetation.

5.

The results from the Criciúma area met better the objectives of this study. The bare coal refuse areas were well identified and localized with a fairly good internal classification. The urban land use classes, identified in order to help the localization of the spoil areas, presented also a good accuracy (figure 2).

The class "industrial areas" identified most of the large industries of Criciúma as well as the ceramic plant near Cocal.

The class "urban area" had a good performance in Criciúma, including the small villages (Metropolitana, Rio Maina,etc.) spreading chaotically towards the northwestern mining axis. The city of Siderópolis was well identified and few commission errors were noted over abandoned surface mines.

The class corresponding to water bodies is present only within the spoil areas. In the strip mine areas it is the location of the abandoned trenches, which became artificial, channel-like acid water impoundments. The presence of water in pyrite-rich spoil areas indicates sometimes traces of abandoned slurry ponds.

The combined distribution of the two refuse classes gives a good description of the large spoil areas both in shape and localization. Coal refuse areas as small as 3 ha were at least localized. The larger ones were localized with their actual shape and size.

The internal classification of the coal refuse areas set a compromise: if we better the classification of the sterile spoils, we would incur into commission errors on the pyrite-rich spoil areas and vice-versa. There are many causes for this similarity among the two refuse classes, namely:

- there is some coal mixed in the sterile spoils originated from non--economic coal layers;

- there is also coal along the haul roads within the sterile refuse area;

- the darkening effect of the shadows caused by the sterile refuse piles;

- the spontaneous combustion of the pyrite-rich spoil areas leaving on the surface the inert part of the coal, which resembles to the sterile spoils.

In spite of these constraints, the classification of the spoil areas showed the following results:

1 - The "sterile refuse" class described well the strip mine near Siderópolis. Omissions occured on the naturally reclaimed areas covered with grasses and shrubs and on the artificially reclaimed areas covered by *Eucalyptus*. This class is also present in the pyrite-rich spoil areas, generally occupying the periphery of the refuse area.

2 - The pyrite-rich spoil areas were well represented by its corresponding class, except for the borders where the sterile refuse class predominates, possibly due to the smoothing characteristic of the radiometric correction procedure.

6. CONCLUSIONS

As a first step towards the utilization of MSS-LANDSAT digital data to monitor coal mine refuse sites in Brazil, the objectives of this study were fully achieved.

The results demonstrate that the discrimination of refuse sites against the background is feasible and this product will be useful in a change--detection survey.

The confusion among the two coal refuse classes can be solved by detailed studies over each one of the large refuse sites, in order to categorize the main classes present in these areas. Actually, this will be the next step of the project running, to be developed on two strip mines: one abandoned and the other active, and on a pyrite-rich spoil area, still to be chosen.

The identification of vegetation stressed by acid mine drainage probably will be possible by a multi-date approach. This will certainly better describe the combined effect of seasonality of vegetation and the variations of the pH values according to the specific hydrologic features of the region.

ACKNOWLEDGEMENTS

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CIDADES

1 - IMBITUBA
2 - LAGUNA
3 - TUBARÃO
4 - CAPIVARI
5 - ORLEÃES
6 - LAURO MÜLLER
7 - URUSSANGA
8 - COCAL
9 - CRICIUMA
10 - UNIÃO
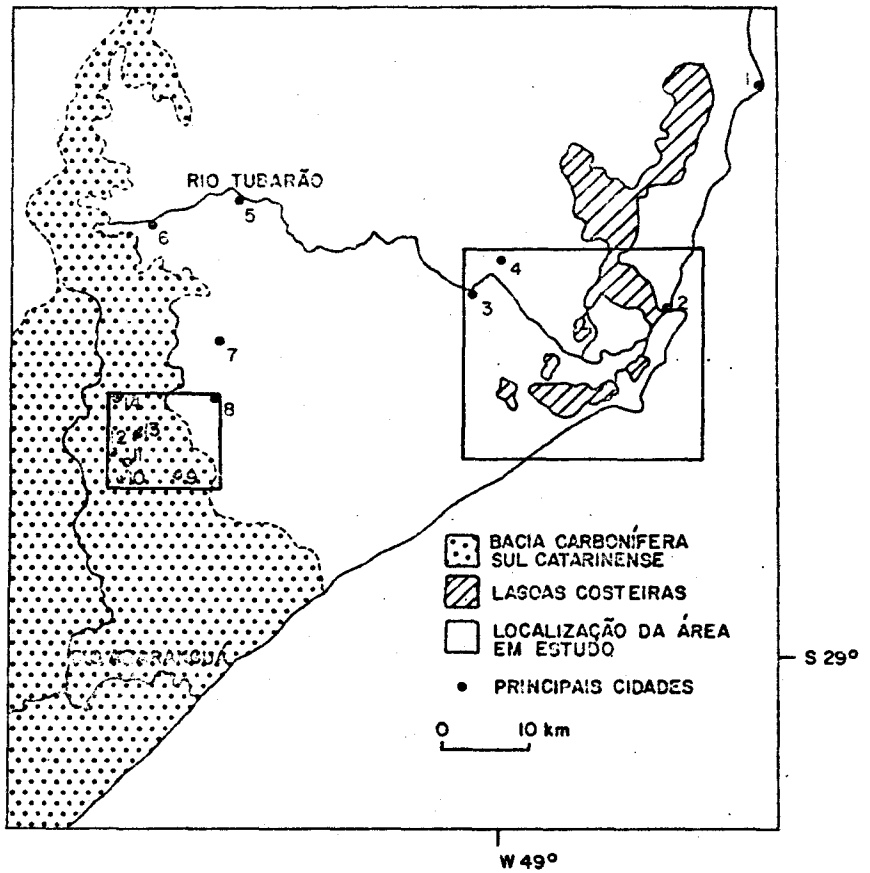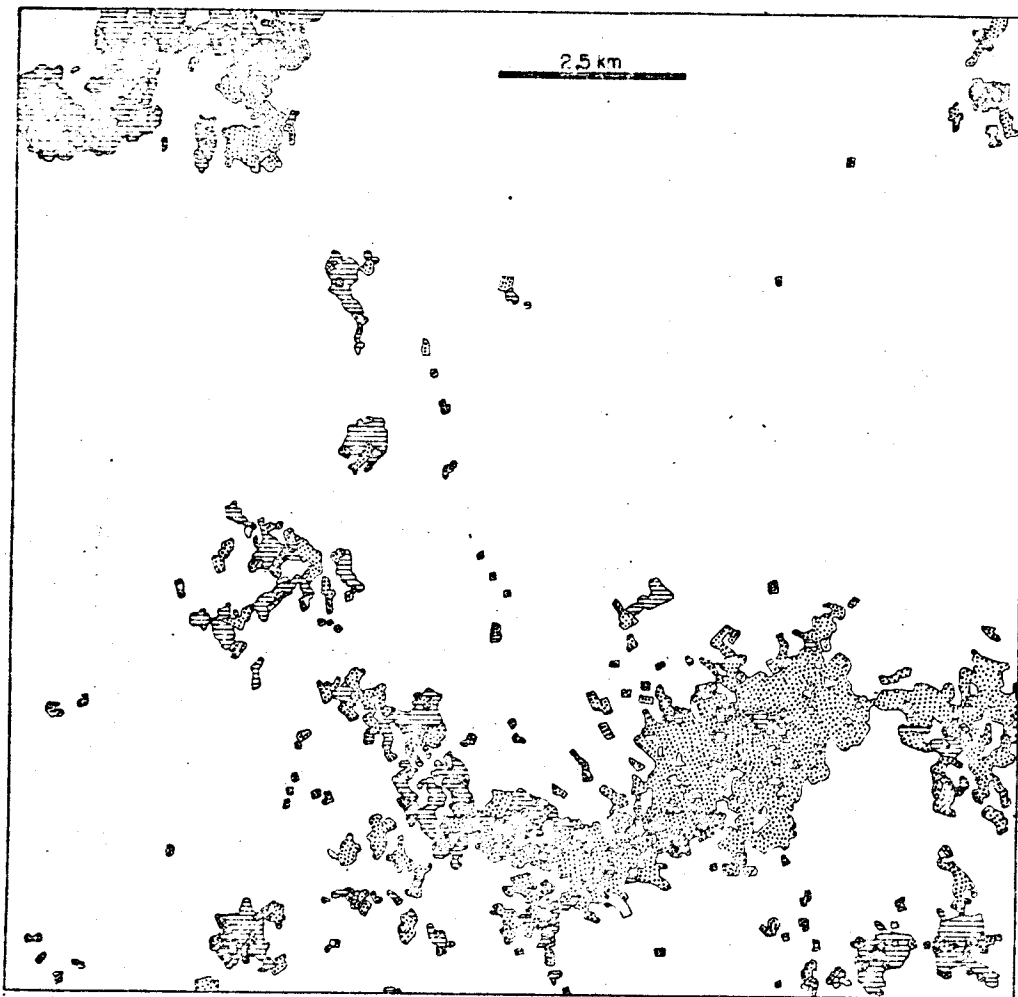11 - RIO MAINA
12 - METROPOLITANA
13 - SÃO MARCOS
14 - SIDERÓPOLIS

Figure 1 - Localization of the study area.

	urban areas - industrial		sterile soils
	urban areas - residential		water bodies
	pyrite-rich spoils		

Figure 2 - Thematic classification, Criciúma area.