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ABSTRACT

This paper presents a methodology for the utilization of a Geographic Information System (INPE/GIS) and orbital remote sensing data to generate soil erosion susceptibility and soil erosion risk maps. Information Planes (IPs) on erodibility, erosivity, lithology and declivity were generated. These data were integrated into INPE-GIS to obtain an erosion susceptibility map. Digital TM-Landsat data were used to obtain a vegetation cover map, that was integrated with the erosion susceptibility map and originated the soil erosion risk map.

INTRODUCTION

In the semiarid section of Northeast-Brazil, erosion processes are mostly related to the low protective capacity of the soil, due to sparse and open steppe-like ("caatinga") vegetation cover, and to the torrential precipitation, that is concentrated in a few months per year. Other factors of relevance, related to soil erosion risks, are: terrain slope (relief) and water absorption capacity of soils, the latter being related mainly to soil texture, lithology and land use/land cover.

In such an extensive region, remote sensing techniques are of great applicability to generate soil erosion risks maps, specially when a Geographic Information System - GIS is used to store and retrieve data and to elaborate thematic maps of interest.

So, the objective of this paper is to present a methodology to generate a soil erosion risk map at 1:100,000, integrating data obtained by the interpretation of TM-Landsat scenes and of existing thematic maps within INPE-GIS, at a test-site in the dry region of Paraíba State.

2. THE INPE-GIS: AN OVERVIEW OF OBJECTIVES

The Geographic Information System from INPE (Institute for Space Research, Brazil) was developed for its remote sensing group, having in mind the following purposes:

- to integrate in a common data base thematic information from maps, census and cadastral data, satellite images and digital terrain models;

- to permit different forms of data input/acquisition, such as map digitalization, images on tapes, etc.;

- to combine several information using special retrieval/recover algorithms and generate new information;

- to generate reports and graphic documents, such as maps, 3D-data, etc.;

- to perform digital image processing operations , using the SITIM, an INPE-developed image analysis system.

The INPE-GIS can work with data in one of these formats: vectorial, raster, DTM, sampled points, contour lines and regular grid. A further description of INPE-GIS, as well as on image processing systems under use, can be found in ENGESPAÇO (1987) and in Souza et al. (1990).

3. THE TEST-SITE: A BRIEF DESCRIPTION

The region under study encompasses an area of about 190 square kilometers, to the west of Paraîba State, NE-Brazil, with geographical coordinates 7°07'30" to 7°15'00"S and 38° 03'45" to 38°11'15"WGr (Fig.1).

The predominant relief features within this area are as well low dissected hills with flat to rounded tops and very dissected ridges showing lengthy crests and "V"-shaped river valleys. The dominant soil types are aridisols (non-calcic brown and eutrophic lithosol). These characteristic soil types from the dry sections of NE-Brazil are poorly developed and strongly affected by sheet and rill erosion.

Table 1 shows a synthesis of the most frequent soil-relief-rock associations within the area under study.

As far as land cover/land use is concerned, three classes are well-defined in the area under study:

1) closed steppe (Brazilian "caatinga densa") located at steep slopes and less devastated areas;

2) open steppe (Brazilian "caatinga aberta") located mostly on flat areas, normally devastated for wood extraction;

3) agricultural activities/bare soil: includes most floodplain areas used for subsistence cultures (mostly maize, beans, cotton, rice).

4. METHODOLOGY

4.1 - Generation of Information Planes (IPs)

This section refers to the generation of IPs on declivity, erodibility, erosivity, lithology, vegetation cover and its insertion in INPE-GIS (Fig.2 - Flow chart of the methodological steps).

A) Declivity

This IP was obtained using the following procedure:

- Insertion in INPE-GIS, via digitizing table, of contour lines from topographic sheets at 1:10,000 (height interval between contour lines: 40m).

- From contour lines an intepolation of the regular grid is performed.

- A DTM image is generated in order to obtain a refined grid with 30 x 30m resolution.

- The calculation of declivity is made from the DTM image. Using a density slicing algorithm, the declivity was grouped in the following slope classes (in %): 0-3; 3-8; 8-20; 20-45 and > 45.

It should be mentioned that the 1:10,000 topographic sheets were used for digitization instead of those at 1:100,000, because the former ones presented a much higher number of precise height points. This helps to use the interpolation method to determine the declivity classes.

B) <u>Soil erodibility</u>

To obtain this IP, those values on erodibility of the superficial soil horizon, determined by Silva et al. (1980) for the soils of Paraîba State, were considered. His method is based on the sand/silt ratio, on the content of organic material, soil structure and permeability, to determine the erodibility of each soil type.

Based on the Paraîba State Soils Map at 1:400,000, the area under study was divided into two classes: 1) low erodibility (< 0,20) referring to eutrophic litholic soils, 2) high erodibility (> 0,20) referring to brown non-calcic soils (Fig.3A).

After inserting each class in INPE-GIS through a digitizing table, the vector data were converted to the raster format (image), with the same resolution as the first IP.

C) <u>Rain erosivity</u>

The procedure to obtain an IP of rain erosivity using a GIS can be divided in two steps: 1. data preparation and 2. input to the GIS.

Data preparation consists on the evaluation of precipitation data and on the calculation of mean annual rain erosivity from these data. To perform this calculation, a set of 44 years on precipitation obtained from the four meteorological stations within the area of study was used, following a suggestion by Bertoni & Lombardi (1985), to whom data of total rainfall from a time span of 20 years or more would suffice to estimate the mean annual erosivity, with a relative precision.

The calculation of mean annual rain erosivity from these data is based on the following equation by Leprun (1981):
$R = 0,13\ P^{1,24}$, where R is the mean annual erosivity and P is the mean annual precipitation. This author correlated the total annual rainfall with Wischmeiers' (1978) factor

R, specifically for each of the climatic zones of NE-Brazil and found a high correlation between R and P.

Data on erosivity were plotted on a topographic sheet at 1:000,000; other iso-erosivity lines where drawn by hand. Since, according to Jaccon (1982), the influence of relief on rainfall distribution is negligible for this region, the main traits of relief were not considered while drawing the iso-erosivity contours.

The input to INPE-GIS of the qualitative erosivity classes obtained ("high", "medium", "low") is made again via digitizing table, followed by the conversion of data from vector to raster format (Fig. 3B). The procedure used to digitize the IP on lithology for the area of interest is similar to that described under item A above (Fig. 3C).

D) Vegetation cover

The IP on vegetation cover was obtained from TM-Landsat images, according to the following methodologic steps: geometric and atmospheric correction, vegetation index, enhancement by linear stretch, transformation of vegetation index into thematic images and insertion of thematic images in INPE-GIS. In order to obtain a soil erosion risk map, the vegetation cover density was considered as a factor that could reduce or improve erosion processes. The dense caatinga in the region under study is the vegetation cover that best protects the terrain against erosion.

4.2 - Data integration

To permit the integration of IPs, cross-functions available at INPE-GIS were used. These functions consist of logic operations that allow to cross up to 10 information planes using logical operations "AND", "NOT", "OR" between classes. They can be applied to qualitative variables and the operations between these classes must be defined in a file where the possible crossing possibilities are declared.

In the semiarid section of NE-Brazil, the declivity of slopes was considered the main factor responsible to encroach soil erosion. Being so, in order to obtain the map on susceptibility to soil erosion, the file with the crossing possibilities was defined as follows: for each class of declivity a grade on limitation to erosion susceptibility is assumed (Table 2).

5. Discussion of results

After a visual comparative analysis between the IPs on declivity classes (Fig. 4) and on digitized contour lines, a relationship between them can be observed. This indicates that the IP generated at INPE-GIS is compatible in quality with the 1:100,000 scale. The geometric correction of images, performed by the function "register image on map", showed a very good result probably due to the use of recent (1985) and great scale (1:10,000) cartographic products, that permitted the acquisition of precise control points.

The integration of data using the program " CROSS" allowed simple changes in the file of "CROSSING POSSIBILITIES", thus enabling the acquisition of new classes at the resulting map in a very practical and fast way.

The obtainment of the map on soil erosion susceptibility (Fig. 5) demonstrated that, in order to integrate IPs with the limits of classes that do not coincide, it is necessary to elaborate a file, including all possible crossings/combinations between classes, to avoid blank areas in the resulting map.

The methodology proposed in this study indicates the possibility to obtain maps on soil erosion susceptibility (Fig. 5) and on soil erosion risks (Fig. 6), integrating as well originally quantitative (erodibility, erosivity and declivity) with qualitative information (such as lithology). To do that, it is necessary to "slice"the values in classes and to define different degrees of limitation.

6. Final remarks

The methodology presented here is ideally applied to large areas, where other information, besides that obtained from remote sensing data, is scanty.

Nevertheless, in future works using this methodology, some limitations of it should be taken into account, namely:

1. The INPE-GIS is based on a PC equipment, with limitations of storage and processing capacity. Presently the Image Processing Department at INPE is implementing a GIS to operate on UNIX workstations with a higher capacity of storing and data manipulation.

2. The limitations of optical sensors (TM and SPOT) to cloud cover. This is a typical Brazilian problem, as a tropical country, that will be solved in part with data to be obtained in the 90's from spaceborne SAR systems.

3. The availability of very limited data on precipitation and on erodibility of soils puts limitations to this study, since the low density of information imposes medium to small scales of work.

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TABLE 1

SOIL-RELIEF-ROCK TYPE ASSOCIATIONS IN WESTERN PARAIBA STATE

SOIL	RELIEF	ROCK
Association of eutrophic litholic + rock outcrop	Low to strong dissected hills	granitoids
Association of eutrophic litholic + rock outcrops Association of eutrophic litholic + red-yellow podzolic + rock outcrops	Low to moderately dissected hills	gneiss
Association of brown non-calcic + eutrophic-litholic Association of eutrophic litholic + rock outcrops	Low to strongly dissected hills	shists

TABLE 2

SUSCEPTIBILITY TO SOIL EROSION AS RELATED TO DECLIVITY OF RELIEF

SUSCEPTIBILITY	DECLIVITY (in %)
Nil	0-3
Low	3-8
Moderate	8-20
Strong	20-45
Very strong	>45

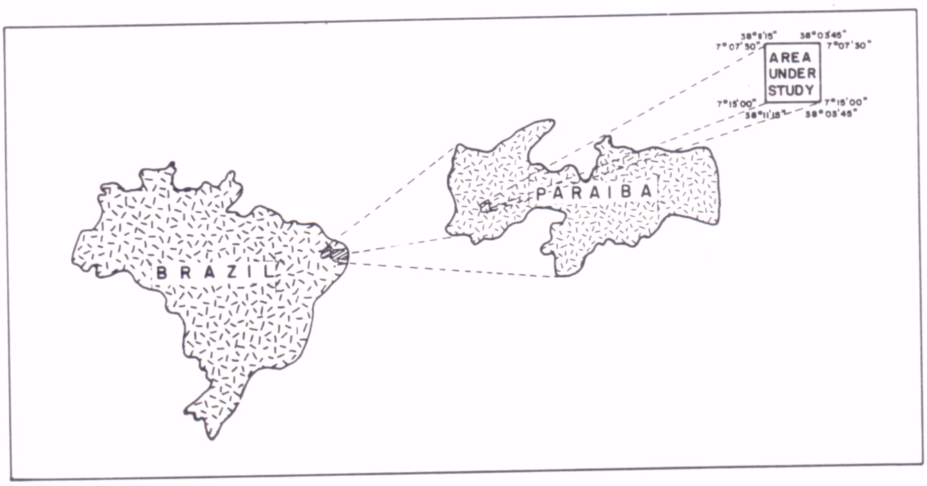

Fig. 1 - Location of region under study.

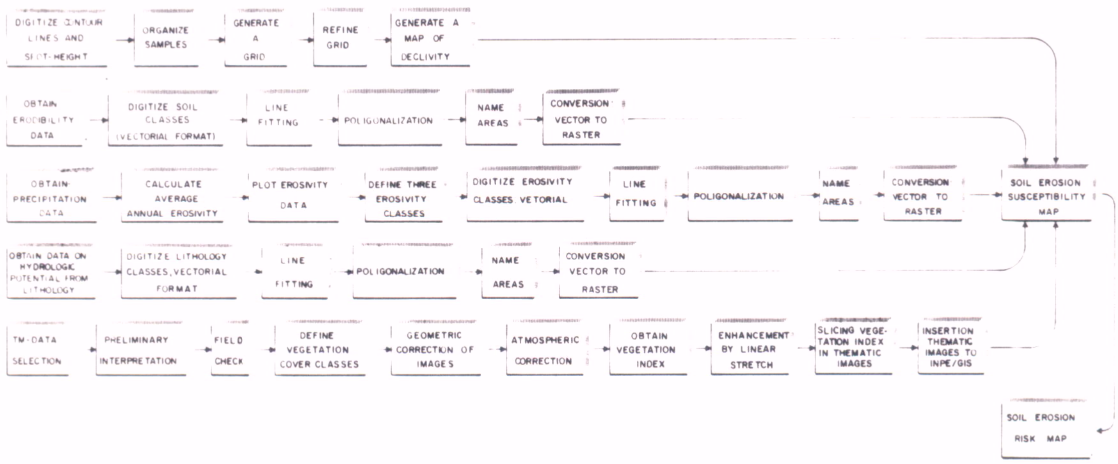

Fig. 2 - Flow chart of methodological steps.

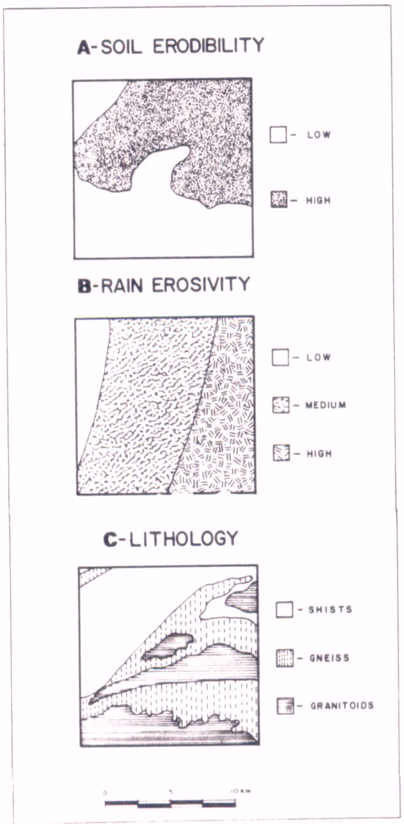

Fig. 3 - Information planes on vector format.

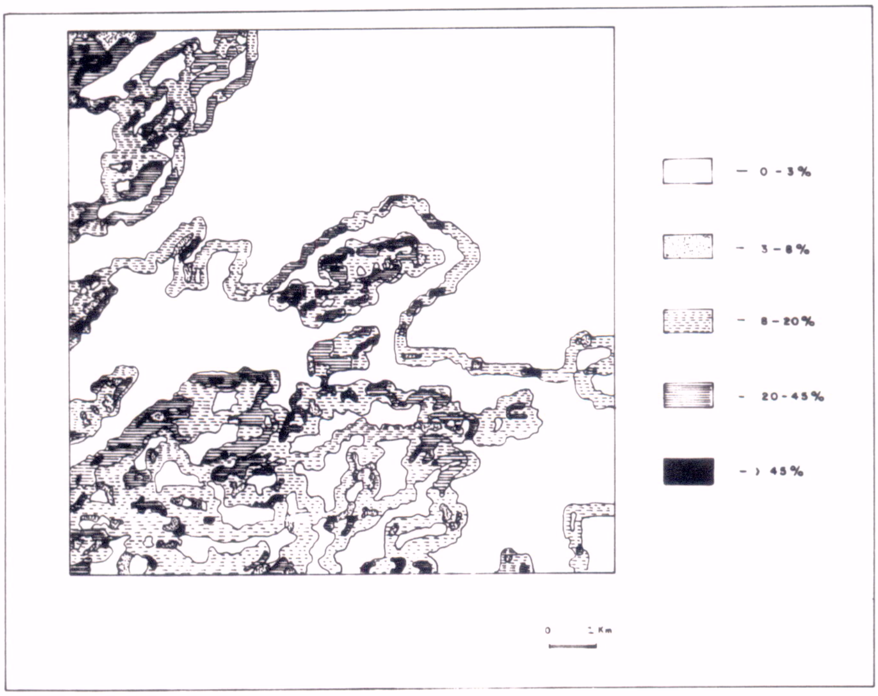

Fig. 4 - IP on declivity classes.

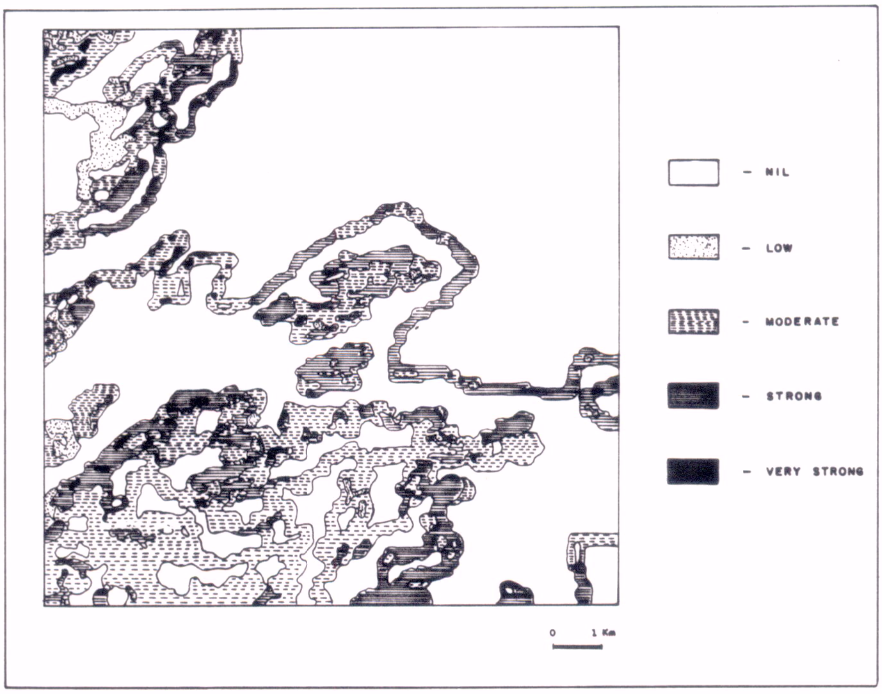

Fig. 5 - Map on soil erosion susceptibility.

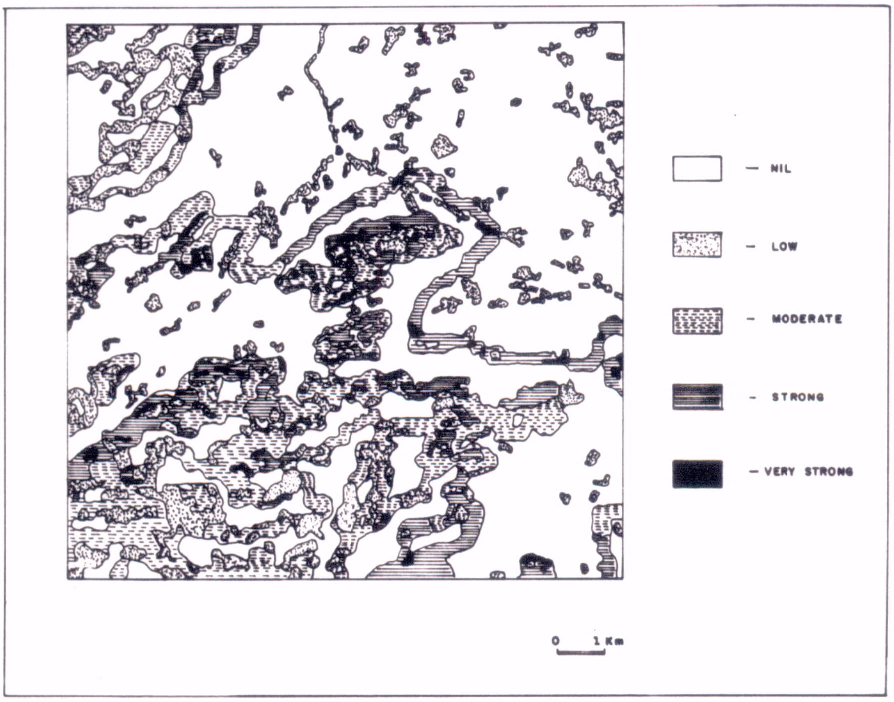

Fig. 6 - Map on soil erosion risks.