REMOTE SENSING DATA AND GEOGRAPHIC INFORMATION SYSTEMS FOR THE CHARACTERIZATION OF AREAS OF SOIL EROSION.

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ABSTRACT:

This work presents an integration method for using Landsat/TM imagery and maps as information to characterize areas which are susceptible to erosion in hydrographic basin in the State of Sao Paulo (Brazil). Information describing the physical environment (slope, length, soil erodibility and rainfall erosivity) were integrated into a Geographic Information System (GIS). The Natural Erosion Potencial (NEP) was obtained. The USLE C factor was obtained from land use maps derived from the interpretation of enhanced TM Landsat 5 Imagery. Those data were integrated to the Natural Erosion Potencial with the GIS in order to provide an estimate and the spatial distribution of areas with erosion risk.

KEY WORDS: Digital Image Processing, GIS, Soil Erosion

1. INTRODUCTION

The concept of sustained development orignates an increasing effort for the definition of prospective methods of environmental impact assessment and planning (Doyle, 1991). One approach considers the use of monitoring indices designed to detect and to evaluate disturbance processes at regional scale (Westman, 1985).

The soil loss represents a serious obstacle to agricultural sustained development in Brazil (Bertoni and Lombardi Neto, 1985). Planning and management technologies seek for methods and strategies to land conservation, while preserving production rates and socioeconomic rural integrity (Nortcliff, 1986). The lack of soil loss control programs frequently results in the destruction of the agricultural structure and in the decrease of resilience and stability of natural and anthropogenic environments.

The detection and assessment of erosion processes through remote sensing and GIS technologies has been proved to be an operational approach (Bocco and Valenzuela, 1988; Pelletier, 1985; Pickup and Nelson, 1984; Roo et al., 1989; Walsh, 1985). The integration of data from both digital systems may be optimised by the use of conceptual models. The application of the Universal Soil Loss Equation (USLE) is an example of this strategy. This model is a powerful tool for erosion studies, widely used by conservationists and planners (Foster et al., 1981; Renard et al., 1991).

This study was initially designed to evaluate the performance of remote sensing and GIS in the investigation of soil loss at regional scale (1:50000). It was intended to optimize the use of the universal soil loss equation in a digital environment, taking into account the potentialities of integrating remote sensing and ancillary data in GIS. Another objective was to define monitoring indices to evaluate erosion processes in agricultural watersheds and to support initiatives of planners and environmentalists.

The area under study comprises a median size agricultural watershed (aprox. 200 km2), situated at the NW portion of São Paulo State, Brazil. This watershed presents a variable relief, with almost levelled areas to sections of steep slopes. The soils map comprises 6 great pedologic groups, mainly with mesotrophic patterns. Agricultural production is concentrated at the lower and middle portion of the basin, represented mainly by sugar cane plantations, corn fields and introduced pastures. The lowest portion is delimited by a hydro-electrical power plant (Barra Bonita), and the water reservoir was formed at the confluence of Piracicaba and Tiete rivers.

2. METHODOLOGY

The soil loss rate was estimated by using the USLE (Wischmeier and Smith, 1965). This model was used as a prospective tool to investigate the major factors that determine or contribute to the soil loss patterns. This equation combine the influence of climatic, edaphic, topographic and cultural features to determine soil loss rates at a semi-quantitative level (Briggs and France, 1982).

The climatic component of USLE refers to the erosion potential or erosivity by rainfall (factor R). The value used in this study was obtained from a isoerodent map of the São Paulo State. This map is based on field observations collected by a gauge grid scattered over the whole State. The attribute R was considered constant for the whole watershed, with a mean annual value of R = 625 tmm/ha/y (Bertoni and Lombardi Neto, 1985).

Factor K - erodibility - corresponds to the intrinsic susceptibility of each soil group to erosion processes. This attribute was obtained introducing a soils map into a GIS and then converting it to specific values of erodibility (Bertoni and Lombardi Neto, 1985).

The topographic factor is composed by the parameters (S) slope steepness and (L) slope length, integrated as follow:

$$(LS) = (0.00984 * L^{0.63} * S^{1.18})$$

both attributes sampled directly from a topographic map at 1:50000.
Cultural factors (C and P) represent the influence of human actions upon soil loss patterns. It is composed by the factors land use and management (C) and conservationist practices (P). The former was defined by using TM imagery; the latter (P) was considered constant (P = 1.0), representing the worst condition, i.e. absence of any conservationist practice.

The detection of land use patterns from remote sensing follows a two step procedure. First, the imagery, corresponding to the winter season of 1990, was submitted to an atmospheric and geometric correction. The resultant imagery represents a geocoded data set, referring to the same cartographic projection used to define the project at the GIS environment.

The imagery, composed by the six bands of the reflective spectrum, was processed by a supervised classifier, the Maxver algorithm. Initially 12 thematic classes of land use were defined. After the classification, these classes were re-classified to 8 generic land use patterns, representing: (1) annual crops, (2) sugar cane plantations, (3) Pinus forest, (4) native vegetation, (5) barren soil, (6) native pasture, (7) managed pasture and (8) urban zones.

Specific C values were derived from land use patterns based on experimental field and laboratory data. These data describe the contribution of each cover type to the protection of soils against erosion.

An analytical procedure was applied at a GIS, integrating both ancillary data and remote sensing data using the USLE. At first the Natural Erosion Potential was calculated as follows:

$$NEP = R * K * (LS)$$

Then the final index, expectation of soil loss (A), was obtained by the integration of NEP and combined factors C and P.

The monitoring indices were defined considering the following relation:

$$CI = A/At \quad \text{and} \quad DI = CP - CPt$$

where CI = critical index, DI = discrepancy index, A = final product of USLE, At = tolerable soil loss index, CP = observed land use and CPt = land use obtained as follows:

$$CPt = At/NEP$$

The critical index detects areas where soil loss rates are greater than the technical acceptable or tolerable level (CI > 1). The Discrepancy index depicts areas where land use patterns induce to soil loss rates greater than the tolerable level (DI > 0).

3. RESULTS

Initially a preliminary environmental typology (environmental zoning) was defined. This was performed by using ordination and classification techniques over the primary data set. Homogeneous areas concerning both relief features (Tables 1 and 2) and edaphic cover (Table 3) were recognized.

TABLE 1 - CORRESPONDING AREA TO EACH SLOPE STEEPNESS CLASS (S) (IN KM2).

0 - 3	1.30
3 - 6	2.24
6 - 12	3.93
12 - 20	13.94
20 - 40	41.36
40 - 60	18.00
> 60	12.12

TABLE 2 - CORRESPONDING AREA TO EACH SLOPE LENGTH (L) (IN KM2).

0 - 50	3.24
50 - 100	13.53
100 - 200	53.08
200 - 300	22.13
> 300	0.99

TABLE 3 - CORRESPONDING AREA TO EACH CLASS OF SOIL ERODIBILITY (K) (KM2).

0.11 - 0.22	62.54
0.22 - 0.24	6.29
0.24 - 0.30	17.61
> 0.30	6.53

The index NEP was classified in four major intervals, representing areas with weak, moderate, moderate to strong and strong potential of soil loss (Figure 1 and Table 4). It was observed that class four is most frequent at this watershed, corresponding to almost 60% of the absolute area. This index was defined taking into account only physical attributes intrinsic to the environment, without any human intervention. Based solely on this index, the watershed must be considered as highly susceptible to soil loss, requiring an intensive application of conservationist and management practices. More than 85% of the area under study presented rates of soil loss greater than 800 t/ha/y.

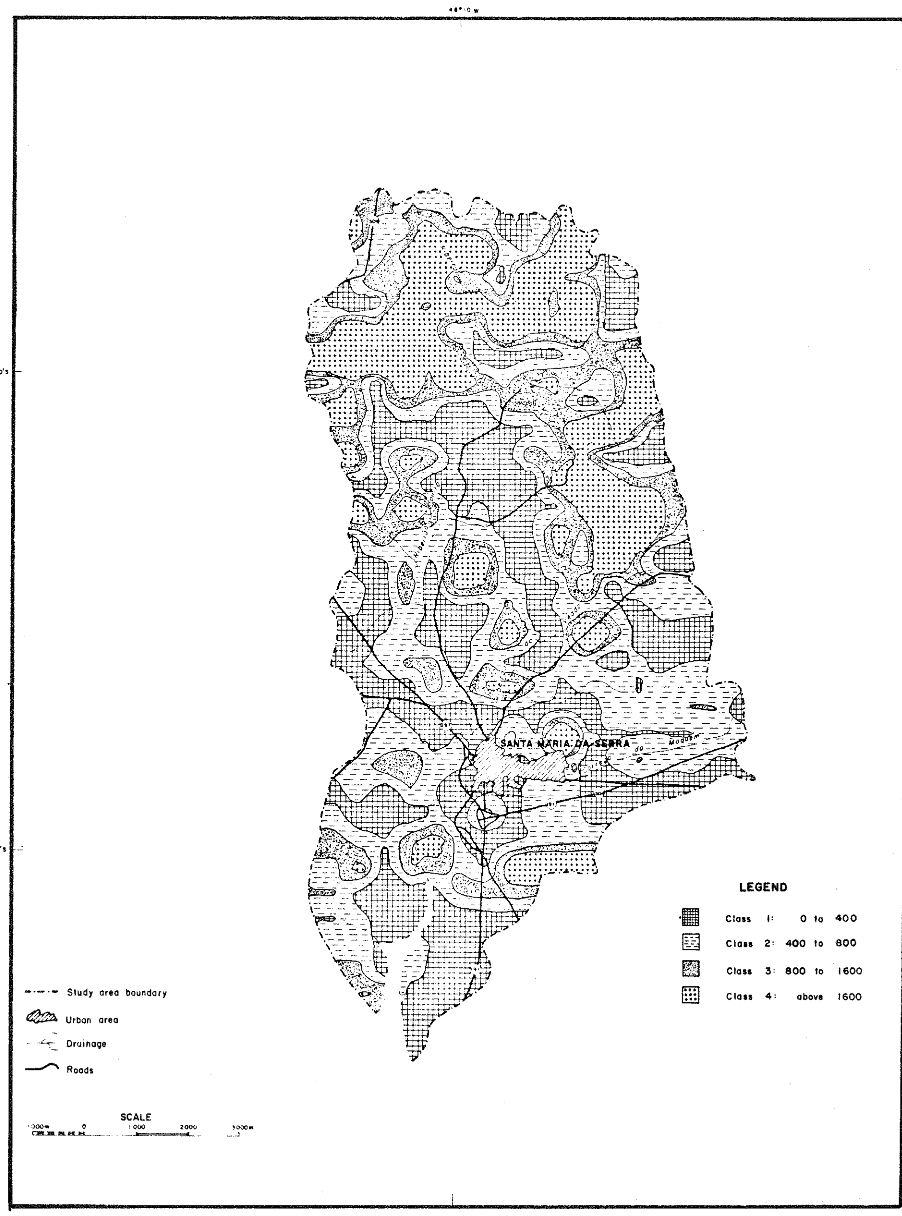

Figure 1 - Natural erosion potential of area under study.

TABLE 4 - CORRESPONDING AREA TO EACH CLASS OF NEP (IN KM2).

Class	(km2)	(%)
0 - 400	4.32	(4.65)
400 - 800	8.79	(9.46)
800 - 1600	27.30	(29.37)
> 1600	52.55	(56.52)

Integrating this index with the land use patterns detected by remote sensing, the expected soil loss rate (index A) was calculated. The intervals adopted to classify these values were defined by the analysis of frequency histograms. Table 5 shows the area (km2) corresponding to each class of A. Table 6 shows the results of the integrated analysis of NEP and the A index (cross tabulation). One can observe the coincidence among each expected class and the four intervals of NEP.

TABLE 5 - CORRESPONDING AREA TO EACH CLASS OF A, EXPECTED SOIL LOSS RATE (IN KM2)

0 - 10	37.12
10 - 25	21.91
25 - 50	7.91
50 - 100	6.59
100 - 500	11.21
500 - 2000	7.52
> 2000	1.42

TABLE 6 - CROSS TABULATION OF ATTRIBUTES NEP OVER A (KM2).

A / NEP	1	2	3	4	5	6	7
1	3.14	0.34	0.15	0.21	0.48	---	---
2	4.97	1.27	0.36	0.38	1.49	0.32	---
3	12.60	5.19	1.82	1.60	2.67	3.42	---
4	16.13	15.02	5.20	4.71	6.31	3.76	1.42

The monitoring indices present a synoptic result. About 40% of the watershed area was classified as being in a critical situation:- expected soil loss at the upper tolerable level. The discrepancy index shows that almost 80% of the whole area was classified as submitted to an inadequate land use pattern.

A cross tabulation analysis of the monitoring index over NEP, denoted that about 65% of the area classified as discrepant corresponds to parcels of strong natural potential of soil loss, while only 26% was situated in areas of adequate land use patterns.

Almost 65% of the critical areas were presented strong NEP. Non-critical areas were observed over weak NEP (50%) and moderate to strong NEP (30%).

A discriminant and step-wise analysis were carried out to evaluate the contribution of each primary attribute (independent variable) over the variability of A index. Both models showed that NEP is the preponderant independent variable, contributing at about 50% to the variability of the A index. Furthermore, a high correlation index was observed amongst NEP and topographic features ($r = 0.85$ $P < 0.05$).

4. DISCUSSION

The results obtained by this study can be considered as satisfatory. Although there are some impediments for the utilization of USLE at the regional scale, this model has been shown to be powerful enough as to detect and characterize the erosion processes at a prospective level.

The major difficulty to use this methodology in planning programs is related to the high subjectivity observed during processing remote sensing data and the conceptual inconsistency of some attributes of the USLE. Factors like slope steepness and its length provide a preliminary view od the morphological structure of the watershed. Nevertheless, some information suppression may occur during integration analysis in GIS. Also, factors like slope steepness as defined by USLE, do not discriminate concave and convex relief forms, although it is quite important for the characterization of land forms.

Attributes like erosivity and erodibility are under strongly influenced by the generalization level and scale of variability. The non-precise definition of a proper scale, imply in non-representative data or incompatibility with the analytical scale adopted at GIS.

The integration of remote sensing and GIS presents some restrictions concerning to (1) dicotomy of data format (vector and raster), (2) subjectivity during acquisition and classification of remote sensing data and (3) absence of an objetive methodology for quality control of the data base during acquisition, analysis and presentation of results.

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