Acta Scientiarum 22(4):1037-1043, 2000.
ISSN 1415-6814.

Use of AVHRR/NOAA-14 multi-temporal data to evaluate soil degradation

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ABSTRACT. This paper presents a methodology for the use of AVHRR/NOAA-14 (Advanced Very High Resolution Radiometer/National Oceanic and Atmospheric Administration) sensor data in USLE (universal soil loss equation) for the identification of soil degradation and the mapping of erosion risks at regional level. To apply USLE equation, remote sensing and GIS (Geographic Information System) techniques were used to define sugarcane plantation areas. NDVI (Normalized Difference Vegetation Index) data acquired from seven different AVHRR images were transformed from gray scale levels to percent of reflectance, because reflectance data are more adequate to get NDVI values. A linear correlation analysis was performed between soil losses ratio and the age of sugarcane to derive the factor C (land use and management) which indicates the soil protection provided by the vegetative cover and it changes gradually as the amount of biomass increases. NDVI data derived from AVHRR/NOAA-14 images were adequate to characterize biomass increase in sugarcane plantations in a 16-month period covering two harvests.

Key words: remote sensing, geographic information system, land use planning,

RESUMO. Uso de dados multi-temporais do sensor AVHRR/NOAA-14 para avaliar a degradação do solo. Este trabalho apresenta uma metodologia para a integração dos dados do sensor AVHRR/NOAA-14 na equação universal de perda de solos (EUPS) para identificar a degradação do solo e mapear os riscos de erosão em escala regional. Técnicas de sensoriamento remoto e sistema de informação geográfica (SIG) foram utilizadas para definir áreas plantadas com cana-de-açúcar. O IVDN (índice de vegetação por diferença normalizada) foi obtido de sete imagens AVHRR, transformadas de níveis de cinza em porcentagem de reflectância. Uma correlação linear foi estabelecida entre o índice de perda por erosão e a idade da cana-de-açúcar, visando a obtenção do fator C (uso e manejo) da EUPS que indica a proteção do solo fornecida pela cobertura vegetal e muda gradualmente com o aumento da biomassa. O IVDN derivado das imagens AVHRR mostrou-se adequado para caraterizar o aumento da biomassa em plantios de cana-de-açúcar num período de 16 meses, cobrindo duas colheitas.

Palavras-chave: sensoriamento remoto, sistema de informação geográfica, planejamento de uso da terra.

Soil is the fundamental natural resource for any nation. However, its misuse may cause several degradation processes, with disastrous results to people's economy and life quality. Soil degradation may be defined as the result of one or more processes that reduce actual soil capacity to produce goods, in both qualitative and quantitative ways.

Erosion has been causing severe damages in the state of São Paulo, Brazil, not only through crop soil losses, but also in urban areas degradation, where a great amount of public investment is expended every year. Being an intensive management crop, sugarcane has caused serious problems of soil degradation and disturbances in water resources, as outflow reduction, sediment transportation and pesticides contamination.

A better understanding of the soil degradation risks and its geographic distribution, as well as where the degradation processes effectively occur, should be the main concern of researchers, planners, and decision-makers involved with land use policy, in order to establish efficient planning and soil management. Such evaluation is particularly important in the present, due to the fast changing of land use in many parts of the world which is frequently the main factor of soil degradation (Chisci, 1981).

The studied area is particularly important due to its strategic insertion into the Mercosul (South Common Market), which was created in 1995 to integrate economically Brazil, Argentina, Paraguay and Uruguay. Prognostics for the year 2010 indicate that the fluvial transportation will reach 13 million tons (25 billion dollars) since cargo will be mostly originated in the Tietê-Pananá waterway surroundings (Cesp, 1996).

The detection and monitoring of the accelerated soil erosion by means of remote sensing techniques may provide data mostly related to the soil surface (Pinto, 1991). In view of this, soil losses assessment through erosion were accomplished in part of Piracicaba river basin to calculate erosion risks under sugarcane plantations using geo-processing and remote sensing techniques.

Methodology

Localization. The area studied has an extension of 68,041 ha, located between co-ordinates 22º30' and 23º00'S and 47º30' and 47º45'W, corresponding to the lower sector of Piracicaba river basin (Piracicaba Environment Compartment) at the middle-eastern region of the state of São Paulo, Brazil, where sugarcane is the main crop, using 76.4% of the area (Figure 1).

Figure 1. Study area location in São Paulo State, Brazil

AVHRR/NOAA-14 images. The polar orbiting environmental satellites operated by National Oceanic and Atmospheric Administration (NOAA) carry the Advanced Very High Resolution Radiometer (AVHRR), a multi-spectral scanner that collects images covering a 2,700-km swath on Earth with a spatial resolution of 1.1 km^2.

In this research, data from satellite 14 were used, because it crosses the study area around 2:30pm local time, thus providing excellent data for vegetation studies. AVHRR images are adequate to vegetation distribution studies and seasonal changing at regional and continental scale, as it follows: a) its 2,700-km swath covers Brazilian territory with a few images; b) daily AVHRR data coverage provides significant image collection to observe seasonal changes or cloud-free targets.

Studies on vegetation coverage through remote sensing may conveniently use spectral-radiance data. Since pigments absorption and water content are highly correlated, only two spectral ranges from the electromagnetic radiation have been used to analyze vegetation biophysical properties. These wavelengths are the visible upper portion (0.6μm to 0.7μm) and the near-infrared (0.75μm to 1.1μm). Values measured by the AVHRR sensor in those two regions may be combined to normalize solar irradiance.

The combination of visible and near-IR wavelengths generates vegetation indices as Normalized Difference Vegetation Index (Tucker and Sellers, 1986). In the present work, the digital counts of AVHRR-1 and AVHRR-2 channels were used. Radiometric calibration was performed following the convention adopted by National Environmental Satellite Data and Information Service (NESDIS) according to Mitchell (1997) for the transformation of digital counts from AVHRR channels 1 and 2 into reflectance values.

Selection of AVHRR/NOAA images. Images were selected from the quick-look to meet the following conditions:

- cloud-free images, for leaving aside cloud-cleaning methods, since the acquisition of sequential images was not feasible for the present work;
- images taken at nadir point, to assure a 1.1 km regular pixel size and allow a better geographical correction;
- adequate time interval between images taking, to allow the coverage of a 16-month period (May, 1996 to September, 1997);

Obviously, such conditions limited images acquisition in some critical periods, like summer, due to intense cloud coverage. On the other hand, image processing was easily done with the selected image set.

Normalized Difference Vegetation Index (NDVI). The NDVI is the difference of near-infrared band (AVHRR channel 2) and visible red band (AVHRR channel 1) reflectance values normalized over the sum of channels 1 and 2. The reflectance values are indicated for deriving NDVI because they are more sensible than the digital numbers (gray level).

Normalized Difference Vegetation Indices (NDVI) were derived from seven AVHRR images through algorithms existent in the Geographic Information System (GIS) compound of algebraic operations applied to channels 1 and 2 of the selected images, as follows:

$$NDVI = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (1)$$

where ρ_1 and ρ_2 correspond to reflectance values of visible band (AVHRR 1) and near-infrared (AVHRR 2) respectively.

The NDVI equation produces computed values in the range of -1.0 to +1.0, where increasing positive values indicate nonvegetated surface features as water, barren land or clouds. NDVI characteristics may be considered an important tool for studying vegetation dynamics. When worked as temporal series, their sensibility in detecting changes in the vegetation-spectral behavior makes them extremely useful for monitoring crops phenological cycles and changes due to crop management.

Townshend and Justice (1986) analyzed the vegetation dynamics using 8-km NDVI images covering Africa. Such images were analyzed through the method of temporal composition to reduce cloud-covering and atmospheric effects. The graphics derived from NDVI data for 1983 and 1984 indicated that different types of vegetation cover present similar phenological characteristics.

Several authors worked with NDVI values for different purposes: Hobbs (1995) obtained promising results by using NDVI values as data to assess herbage production in arid rangelands of Central Australia. Losano-Garcia (1995) monitored the severe drought occurred in Indiana State, USA, with very good results.

NDVI is the determining parameter for correlation with soil loss ratio in sugarcane-cultivated areas. In addition, reflectance figured out in percentage values normalizes data from images taken at different times and situations, what allows a better comparison between them. That is the case of the present study where NDVI images of different times and harvests are compared (Figure 2).

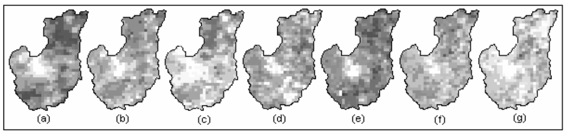

Figure 2. NOAA/AVHRR-14 showing NDVI's images changes in the study area: (a) 05/29/96; (b) 06/15/96; (c)07/23/96; (d) 11/27/96; (e) 04/14/97; (f) 08/19/97; (g) 09/17/97

The Universal Soil Loss Equation (USLE). The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) was used to evaluate actual land degradation of Piracicaba river basin; the results were maps presenting the current erosion and the natural erosion potential aspects. The USLE equation is:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (2)$$

where

A = computed soil loss per unit area (t/ha/year);

R = erosivity (rainfall erosive power) (MJ.mm/ha.h);

K = erodibility (soil susceptibility to erosion) (t.h/MJ.mm);

L = slope-length factor is the ratio of soil loss from a field slope length to that from a 25m length under identical conditions;

S = slope-steepness factor is the ratio of soil loss from a field slope gradient to that from a 9-percent slope under identical conditions;

C = cover and management factor is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow;

P = support practice factor is the ratio of soil loss with a support practice to that with straight-row farming up and down the slope.

Factors R, K, L and S are dependent on natural conditions and the factors C and P are related to land use and management (Figures 3 and 4).

Land use and management (Factor C). Factor C is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow (Bertoni and Lombardi Neto, 1990). The canopy protection of crops depends on the type of vegetation, the stand, the cropstage periods, and also on the different months and seasons. As a consequence, the value of C also varies and measures the combined effect of crop and management practices. Since vegetation cover protects soil gradually during its phenological cycle, it is common to divide the crop year in 5 (five) cropstage periods, for which vegetation cover effects are considered uniform within each period as follows:

- Period D - soil preparation: from tillage to stalk planting;
- Period 1 - planting: from planting to 1 month after period D;
- Period 2 - establishment: from end of period 1 to 2 months after planting;
- Period 3 - crop development and maturing: from 2 months after planting to crop harvest;
- Period 4 - residue: from harvest to plowing.

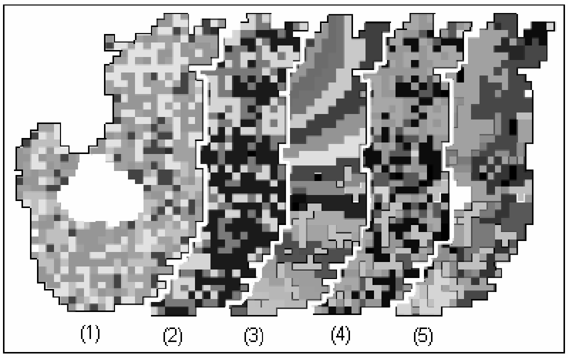

Figure 3. USLE determination: (1) slope; (2) slope-length; (3) erosivity; (4) conservation practices; (5) erodibility

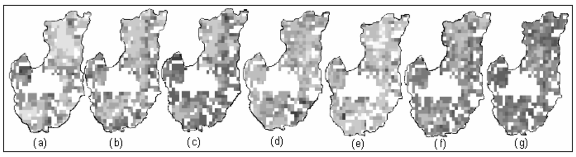

Figure 4. Factor C in the study area: (a) 05/29/96; (b) 06/15/96; (c)07/23/96; (d) 11/27/96; (e) 04/14/97; (f) 08/19/97; (g) 09/17/97

Soil Loss Ratio. Soil loss ratio (SLR) must be computed for each of the five cropstage periods and for each crop, under several conditions (crop sequence, fertility level, yield, crop stubble). These parameters were derived using Bertoni and Lombardi Neto (1990) methodology, using data already established by Agronomic Institute of Campinas (IAC) for the state of São Paulo. The linear correlation between soil-loss ratio values (SLR) and sugarcane's age (days after planting) can be written as:

$$SLR = 0.241 - 0.0005227\,X \quad (3)$$

where X is the age in days, with a correlation coefficient (r^2) = 0.99

Rainfall Erosion Index (EI). Rainfall erosion index was derived from the percentage of rain effectively fallen in the test area. As a result, factor C was derived from the soil loss ratio multiplied by the percentage of annual erosion-index distribution, both limited in each period by AVHRR image taking.

Field control. To achieve the necessary correlation between field data and NDVI data determined from AVHRR images, a test area with 900 hectares was established as "ground truth", composed by 104 sugarcane plots. Seven images of the area were created in which sugarcane age data (days after planting) were attributed to plots. Sugarcane age corresponded to AVHRR images acquisition dates (05/29/96; 06/15/96; 07/23/96; 11/27/96; 04/14/97; 08/19/97 and 09/17/97). Through the equation (3), each plot assumed soil loss ratio values.

Since SLR and NDVI are time related, a correlation between them was established, aiming to derive a proper equation to determine SLR in the AVHRR/NOAA images which allowed to reach factor-C values (Figure 4). After being geo-referenced, those seven ground images were overlaid on the AVHRR images, so that the sugarcane plots SLR values could be correlated with the average NDVI corresponding values, resulting in a new adjustment equation:

$$SLR = 0.346 - 0.553(NDVI) \quad (4)$$

with coefficient (r^2) = 0.71

Erosion risk. Bergsma (1983) states that erosion risk may be understood as the probability of erosion events occurring in near future. So, the objective of erosion-risk maps is to show the soil loss prediction under alternative systems of land use and management. For watershed studies, erosion-risk maps allow the prediction of environmental impacts caused by agricultural activities.

The expression "soil loss tolerance" is used to point out the maximum soil erosion intensity in t/ha/year, which will allow the economical maintenance of a high level of productivity indefinitely. In the state of São Paulo, tolerance ranges from 4.5 to 15.0 t/ha/year are a function of soil characteristics (Bertoni and Lombardi Neto, 1990). Deep, medium texture, well drained soils present higher tolerance values. On the other hand, shallow, superficial horizon soils present lower ones.

The expected soil loss intensity may be compared with the soil loss tolerance in a given area, what makes it possible to combine planting and management practices to be adopted where the soil loss is lower than tolerance values, thus providing a satisfactory condition of soil erosion control. To each elapsed time period between the image dates (07/01/95 to 05/29/96; 05/29/96 to 06/15/96; 06/15/96 to 07/23/96; 07/23/96 to 11/27/96; 11/27/96 to 04/14/97; 04/14/97 to 08/19/97; 08/19/97 to 09/17/97) the erosion risk was derived overlaying (dividing) the expected soil loss (USLE's "A" value) layer by soil tolerance layer .

Results and discussion

The erosion risk maps were reclassified resulting in 5 (five) erosion risk classes: *class 1*, less than one time the soil loss tolerance (very low); *class 2*, 1 to 2 times the tolerance (low); *class 3*, 2 to 5 times the tolerance (medium); *class 4*, 5 to 10 times the tolerance (high); *class 5,* more than 10 times the tolerance (very high). Figure 5 shows erosion-risk classes in annual values.

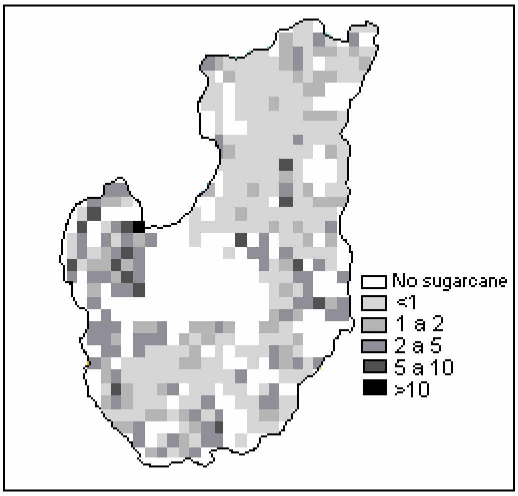

Figure 5. Annual erosion-risk classes in the studied area

A comparison between the erosion risk evaluation using AVHRR data to derive factor C with different ways to assess the same parameter was established in order to certify the accuracy of data obtained by the current work. Cavalli and Lombardi Neto (1998) evaluated erosion risk in the same area with different parameters: C-Factor used was the average of data obtained by conventional methodology for sugarcane plantations in the state of São Paulo; USLE parameters were derived through geographic information system with a pixel size of 125 meters. Figure 6 shows erosion classes distribution in a very similar disposition as shown by Figure 5. The main difference observed in both pictures is the resolution (pixel size of 1000m in Figure 5 and of 125m in Figure 6). Obviously, that is a big difference in local accuracy, but it is important to consider that AVHRR data ought to be always considered for regional scale.

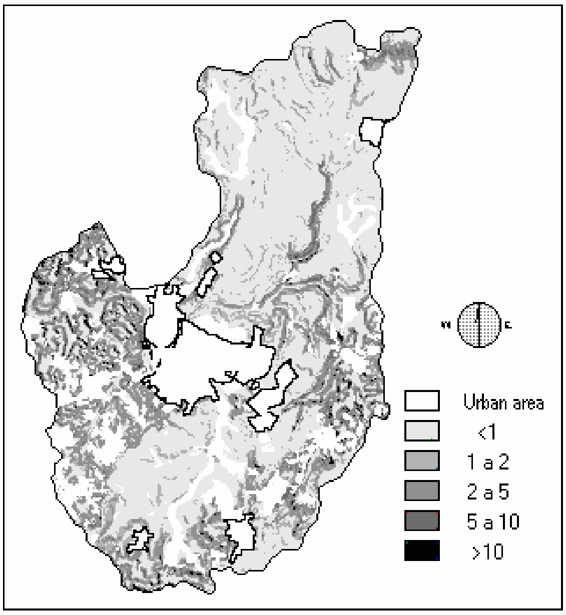

Figure 6. Erosion risk determined by conventional method

Table 1 shows the figures obtained in both work. A correlation index (r^2) of 0.98

between data demonstrate a good result for such a course resolution imagery.

Table 1. Erosion risk classes obtained by different methodologies

Classes		Figure 7	Figure 8
		%	
<1	Very low	56.5	61.3
1 to 2	Low	19.3	13.9
2 to 5	Medium	20.3	19.1
5 to 10	High	3.7	4.7
>10	Very high	0.2	1.0
		100.0	100.0

NDVI values change in the different image dates on sugarcane plantations resulting in different erosion risk figures for the in-between periods. In May, 1996, at the beginning of the harvest (Figure 2-a), NDVI values are high on account of the great amount of green biomass existent in the plots.

As harvest proceeds, NDVI values decrease until the end of harvest period in November (Figure 2-d). It is important to consider that such decrease is not greater due to the ratoons growth, what compensate the soil exposition effect and thus mitigates NDVI decline. In April, 1997, sugarcane crop stands in the top of their phenological development, right before the harvest beginning. In this stage, the green biomass NDVI shows its maximum value (Figure 2-e). The harvest cycle repeats and the vegetation indices start growing once again (Figure 2-f and 2-g).

Table 2 presents the erosion risk classes in the studied sugarcane area and shows average values for the whole period of the research (07/01/95 to 09/17/97) as follows: 56.5% of total area are included in class 1 (soil-loss values are smaller than tolerance ones), which means that the area does not present problems of environmental impacts caused by erosion.

Table 2. Erosion risk classes for sugarcane crop occurring between the image taking

	Erosion risk classes				
Period	1	2	3	4	5
	%				
07/01/95 to 05/29/96	58.58	17.16	19.60	3.67	0.98
05/29/96 to 06/15/96	100.00	0.00	0.00	0.00	0.00
06/15/96 to 07/23/96	100.00	0.00	0.00	0.00	0.00
07/23/96 to 11/27/96	94.61	4.16	1.22	0.00	0.00
11/27/96 to 04/14/97	72,06	17.89	9.07	0.73	0.24
04/14/97 to 08/19/97	99.30	0.70	0.00	0.00	0.00
08/19/97 to 09/17/97	100.00	0.00	0.00	0.00	0.00
Total Period (average)					
07/01/95 to 09/17/97	56.50	19.30	20.30	3.70	0.20

In general sense, sugarcane may be considered among the crops able to cause the lowest environmental impact by erosion. As a grass-like plant, its hairy root system provides a kind of protection net which prevents runoff damages. Besides, the huge amount of leaves rapidly cover the soil, promoting an efficient protection against rain drops impacts on the terrain

The erosion-risk classes 4 and 5 presented an area of 3.9% where soil losses bigger than 5 times the soil loss tolerance values occurred, probably causing environment impacts by erosion.

Since the erosion control mitigation costs for areas occurring in classes 4 and 5 are frequently quite expensive, it would be advisable to recommend the replacement of sugarcane crop by more adequate land use.

Normalized Difference Vegetation Index (NDVI) allowed to observe the vegetative cycle of sugarcane crop during practically two harvest periods (1995/96 and 1996/97) since NDVI data measured in a 16-months series represent the behavior of vegetation cover biomass on Piracicaba Environment Compartment for that period.

USLE and NDVI data processing with the aid of statistical procedure to achieve regression analysis, allowed to establish a methodology for integrate AVHRR/NOAA-14 digital images in the soil degradation studies at regional levels. Furthermore, it was possible to determine C Factor values from spectral reflectance data for application in Universal Soil Loss Equation.

Probably, the environmental impacts caused by sugarcane is mostly due to monoculture, since the exaggerated concentration of continuous crops strengthens the impacts. Yet, when the land is massively used, basic principles of soil natural drainage and gallery vegetation protection are disregarded, which concurs to soil degradation.

The use of analytic methods derived from remote sensing products acquired from AVHRR/NOAA-14 sensor, together with geoprocessing and geographic information systems techniques allowed to obtain data with enough sensibility to characterize soil degradation through rainfall erosion.

The data obtained allow a better planning for sugarcane crop in the region, avoiding possible environmental impact problems and keeping the sustainability for the crop. That is particularly important since the region is critical concerning quality and quantity of water supply both for human and industrial consumption.

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Received on July 28, 2000.
Accepted on September 15, 2000.