THE USE OF REMOTE SENSING FOR SOIL MOISTURE DETECTION: APPLICATION IN THE STUDY OF MASS MOVEMENTS.

CRISTINA Q.T.MAFFRA
JORGE S.CENTENO

FEDERAL UNIVERSITY OF PARANÁ

Geomatic Department
Mail Box: 19001 81531-980

CURITIBA – PARANÁ

BRAZIL

Abstract: In Brazil several areas along the southeastern coast are affected by mass movements, mainly by landslides. Most of these landslides occur during the rain season (from December to April) and are intrinsic related to soil moisture saturation. For soil moisture detection remote sensing in near infrared, infrared and microwaves wavelengths are more indicated. It is because saturated soils show decrease of absorption in infrared region of the electromagnetic spectrum. The present approach uses remote sensing for soil moisture detection through the use of different image processing transformations (NDVI, Tasseled Cap Transformation and Principal Component Analysis of infrared and thermal bands). LANDSAT images from different periods (dry and wet season) were used. The results obtained show that Principal Component Analysis of infrared and thermal bands and Tasseled Cap Transformation have good correlation with a Pluviometric Index and can be applied for landslide prediction/ monitoring modelling.

I. INTRODUCTION

In the last years several studies using remote sensing for soil moisture detection have been developed because the traditional methodologies are generally punctual while the date obtained through remote sensing can be applied to vast areas.

Soil moisture can be understood as a physical parameter which has a spatial and temporal variability, and differ from other parameters as slope, relief that show mainly spatial variation (NEUSCH, 1999). Remote Sensors in near infrared, infrared, thermal and microwaves bring useful information for soil moisture detection.

Moisture is one of the elements that affects soil reflectance in larger wavelengths, as consequence of the high absorption of water in these wavelengths. The amount of moisture will also reduce drastically the vegetation reflectance in wavelengths higher than 1,4 μm (CHUVIECO, 1990).

The objective of this study is to assess the potential of LANDSAT TM data for soil moisture detection.

II. STUDY AREA

A study area located at Florianópolis island and the surrounded area, in Santa Catarina State, South of Brazil was chosen because the amount of natural and induced mass movements (Fig 1).

The area lies in a granitic-gnaissic belt in a geomorphologic unit known as Serra do Taboleiro, where the relief is mountainous and the altitude reaches 1000 meters. In this geomorphologic unit the slopes can be steep and the valleys deep, which is favorable for mass movements.

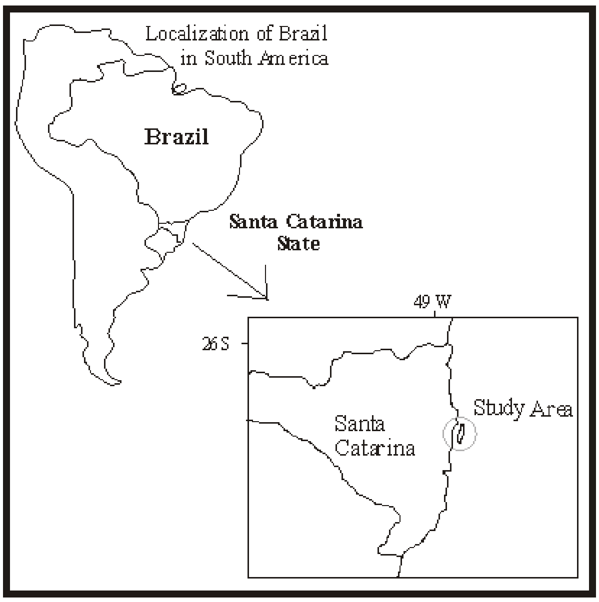

Fig. 1. Localization of the study area.

III. DATA AND METHOD

For this study three LANDSAT images were used. Two LANDSAT 5 images, with all 7 bands, acquired in 04/05/1990 and 18/05/1995 and one LANDSAT 7 image, with all 7 bands, acquired in 07/05/2000.

Daily rain data for the months of May/1990, May/1995 and May/2000 from three pluviometric stations: Rancho Queimado, Garcia and Lagoa do Peri were used for computing a pluviometric index.

The study was developed in the following steps:

Pre-Processing: image registration, atmospheric correction, and transformation of DN values in reflectance values.

Data Analysis: application of the NDVI, Tasseled Cap and Principal Component transformations.

Results: correlation of the results obtained with the pluviometric index through regression statistics.

Conclusion: based on the results obtained.

IV. PRE-PROCESSING

Image Registration

The image registration was performed using a first order polynomial transformations. The RMS ("*Root Mean Square Error*") obtained was lower than 1 pixel. The resampling method used was Nearest Neighbor. This process was chosen because it has the advantage of preserving the original grey values and is fast, but as disadvantage it can generate geometric discontinuities in the order of 0,5 pixel (ENVI, 1997). After the registration, control points were collected to verify the accuracy, which was between 1 and 1,5 pixel. In order to decrease the influence of the error in the final results, a window of 3X3 pixel were used when the values of the transformations were measured. In this way the geometric error was minimized.

Atmospheric Correction

The method used for atmospheric correction is the one described by Chavez (1996), based on the linear regression between bands. This process eliminates the interference of the Rayleich dispersion.

Transformation of DN to Reflectance

As in this study values obtained through Tasseled Cap transformation, NDVI and Principal Component analysis are compared with a physical parameter, moisture, through a multitemporal analysis, the DN must be converted to reflectance values.

The process is divided in 2 steps: in the first, radiance is calculated and in the second the reflectance is calculated.

Radiance calculation: For the sensor radiance calculation the following expression was used:

$$Lsen= a0_k+a1_k\ DN_k$$

where

$a0_k$ and $a1_k$ are the offset and gain respectively.

DN_k are the digital values for each band

The Lsen corresponds to the radiance captured by the sensor.

Reflectance calculation: to calculate the reflectance values the following expressions were used:

$$\rho = K\ \pi\ Lsen\ K/\ E_{0,k} \cos\theta$$

where θ is the zenithal angle;

$E_{0,k}$ is the extraterrestrial irradiance for each band of the spectrum;

K is the corrector factor of the distance Earth - Sun calculated through the following expression.

$$K=1+0.0167(\sin\pi\ (2\ (day-93.5)/365))^2$$

V. DATA ANALYSIS

NDVI, Tasseled Cap and Principal Component Transformations

After convert the DN to reflectance values the NDVI index, the Tasseled Cap transformation and the Principal Component Analysis between bands TM7 and TM5 and between TM6 and TM4 were performed.

For each pluviometric station (Rancho Queimado, Garcia and Lagoa do Peri) 3 points in different slopes (convex slope, concave slope and strait slope) were chosen in vegetated areas and also in bare soil areas. In each image the same points, in a 3X3 window, were measured, corresponding to real data.

Result Analysis through linear regression

A linear regression was performed using the values obtained in the transformations and the values of the pluviometric index for each different pluviometric station.

For each image, the pluviometric index used was calculated based on the accumulation of rain (in mm) of the 3 days before the date of acquisition. According to a study developed in the coastal area of Sao Paulo State, a value between 100 mm and 120 mm or above is considered critical for developing landslides in this area (CEDEC, 1996). These values were used as reference in order to compare the date obtained by the different transformations for soil moisture detection.

The image of 2000 was used to study the relationship within a rain period, with high rain cumulating index. The image acquired in 1995 was used to study the spectral answer in the absence of rain (dry period) and the image acquired in 1990 to study the spectral response with the presence of low amount of rain.

VI. RESULTS

Correlation of the results obtained with the pluviometric index through regression statistics

1) NDVI

The NDVI index was chosen because its results reveal the state of vegetation and soil moisture can be indirectly estimated from it (KOREN & KOGAN, 1995).

The relation between the NDVI results and the pluviometric index was very poor and a direct relation could not be observed. The correlation coefficient value (ρ) obtained for a linear model (linear regression analysis) was 0,17 or 17% which means low correlation.

As the data distribution suggested a parabolic form, a non-linear correlation analysis was performed using a second order polynomial but the observed correlation was 18,75% with does not represent an improvement.

Tasseled Cap Transformation

The results obtained suggest that the values obtained with this transformation vary proportionally to the pluvimetrical index.

When performing the linear regression between the Humidity component of the Tasseled Cap values and pluviometrical index the correlation was ρ = -54%. The data distribution suggested a parabolic form and a non-linear regression using a second order polynomial was performed.

The result obtained (adjusted polynomial) was:

$$Y= -49.73939 -1,03545X+0,0094X^2 \qquad (1)$$

where:

X is the estimated pluviometrical index value;

and

Y corresponds to Tasseled Cap values.

From (1) the correlation coefficient was calculated and the result obtained was ρ =0,70 or 70%, which indicates high correlation, if we consider that the studied variables correspond to physical parameters and natural phenomenon.

For the other bands (Brightness and Greenness) both, linear and non-linear regression, were performed and the results were:

for Brightness band ρ = 0,47 for linear regression and ρ = 0,38 for non-linear regression;

for Greenness band, ρ =-0,62 for linear regression and ρ = 0,65 for non-linear regression.

Areas with bared soil were also studied and the final results were considered also satisfactory. For the HUMIDITY band a correlation value of ρ = -0,88 was obtained, for the GREENESS band ρ=0,74 and for band BRIGTNESS ρ = 0,78. In all of these cases the correlation obtained can be considered high. Nevertheless, while studying soils, a lower number of points could be measured, since it is difficult to obtain pure soil pixels in the region. Therefore, the results should be seen with care.

Principal Component Analysis

According to KNIPLING (1970) for wavelengths higher than 1,4 μm there is a notable definition of moisture on the vegetation spectral answer because there is a big influence in the internal structure of the leaves. In this way the principal component analysis of bands that covers these wavelengths (infrared) would bring information in its first components (the components which indicate high affinity between bands). Higher values could indicate places with higher soil moisture and lower values could indicate lower soil moisture values.

The Principal Component analysis was applied between middle infrared bands (TM5 and TM7) and between near infrared and thermal bands (TM4 and TM6).

When the linear regression between the first component of TM5 and TM7 and the pluviometric index was performed, the correlation coefficient obtained was ρ = -0,72. Between TM4 and TM6 it was ρ = -0,59 or 59%. When the linear regression was performed between the second component and the pluviometric index the correlation decrease to ρ = -0,08.

VII. CONCLUSIONS

The results obtained until now suggest that both Tasseled Cap transformation and the first component of the Principal Component Analysis between bands TM5 and TM7 and between bands TM4 and TM6 present good correlation with the pluviometrical index (Tab 1).

As the distribution of the observations suggest a parabolic form, non-linear regressions were performed. In most of the cases a better result was obtained with the non-linear regression (Tab 2).

The results suggest that the relationship between the pluviometrical index and the spectral indexes, mainly with the Tasseled Cap are not linear.

The NDVI index was the one with worst results, with low correlation in linear and non-linear regression, This result could be understood through the absence of a detailed vegetation mapping and a better precision in slope determination.

Based in the results obtained, the non-linear regression model with second order polynomial application allows the prediction of the pluviometrical index through the HUMIDITY band of Tasseled Cap transformation. Values from band HUMIDITY lower than - 65 suggest rain accumulation higher than 100 mm, which corresponds to the index of ALERT to landslide deflagration. Of course, when the variables as vegetation and lithology vary, the model will also change, but the results indicate that it is possible to use Tasseled Cap and Principal Component analysis to differentiate areas with higher probability of landslides occurrence after the model has been established.

It is believed that with detailed information of other variable as slope, vegetation, soil type etc., which mask the presence of soil moisture in a image, the result can be improved and, in this way, contribute for the elaboration of a model for mass movement prediction.

REFERENCES

Cedec – Coordenadoria estadual de Defesa Civil. "Curso de Treinamento de equipes municipais (PPDC)". São Paulo, p.p.26, 1990.

Chavez, P.S. "Digital Merging of Landsat TM and digitized NHAP data for 1:24.000 – scale image mapping". Photogram. Engineering Rem. Sen., v..52, p.p. 1637-1646, 1986.

Chuvieco, E." Fundamentos de Teledeteccíon Espacial". Ediciones Rialp, 1. ed, Madrid, p.p.420, 1990.

Envi. "The Environment for Visualizing images". Tutorials, 1997.

Knipling, E.B." Physical and Physiological basis for the reflectance of visible and near - infrared radiation from vegetation". Rem. Sens. Environment, v.1, p.p. 155-159, 1970.

Koren, V.and Kogan, F. " Parametrization of Hydrological Model using NOAA/AVHRR data". IGARSS' 95, IEEE, 1995.

NEUSCH, T. "Multi-Frequency and Multi-Polarization Synthetic Aperture Radar for Modelling Hydrological Parameters". PhD – Thesis, University of Karlsruhe, Karlsruhe, p.p.128, 1999.

Table 1 – VALUES OF LINEAR CORRELATION COEFFICIENT OBTAINED AMONG THE DIFFERENT SPECTRAL TRANSFORMATIONS AND THE PLUVIOMETRIC INDEX.

VEGETATION								BARE SOIL		
	NDVI	I COMP. TM4/ TM6	I COMP. TM5/ TM7	II COMP.	TAS. CAP BRIGH TNESS	TAS. CAP GREE NESS	TAS. CAP HUMI DITY	TAS. CAP BRIGH TNESS	TAS. CAP GREE NESS	TAS. CAP HUMI DITY
ρ	0,17	-0,59	-0,72	-0,08	0,47	-0,62	-0,54	0,78	-0,74	-0,88

Table 2 – VALUES OF NON-LINEAR CORRELATION COEFFICIENT OBTAINED AMONG THE DIFFERENT SPECTRAL TRANSFORMATIONS AND THE PLUVIOMETRIC INDEX (USING A PARABOLIC FUNCTION).

VEGETATION				
	NDVI	TASSELED CAP BRITNESS	TASSELED CAP GREENESS	TASSELED CAP HUMIDITY
ρ	0,19	0,38	0,65	0,70