# Using Landsat Images for Studying Land Use Dynamics and Soil Degradation - Case Study in Tamduong District, Vinhphuc Province, Vietnam

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#### Abstract

Tamduong district, Vinhphuc province, is representative for vast areas in the north of Vietnam where soils are strongly degraded and erosion has led to patches of bare soil with exposure of parent material, and crop yields on these soils are strongly reduced. The aims of this study are to apply satellite imagery for the assessment of the extent of soil degradation and implementing the results to the whole middle altitude area of North of Vietnam. Satellite images Landsat MSS in 1984 (4 bands), TM 1992, 1996 and 2000 (6 bands) were used for creating maps of the Color Composite and Band Ratios. From these images, bare and degraded soils were identified and extracted. Classified maps of the Band Ratios G/R and R/NIR for the year 2000 were established on the basis of new soil maps and ground truth data. The best band ratio, R/NIR, was selected for further processing and classification base on visual interpretation. The classified map of degraded soils, based on the R/NIR band ratio, matched well with the soil survey map and the field checks with an overall accuracy of 73%. Land use and soil degradation dynamics were reconstructed for the period 1984 to 2000 and degraded soil areas in the district were established at 2440, 3280, 2190 and 2580 ha, for 1984, 1992, 1996 and 2000 respectively. Hot spots from the Band Ratio imagery appeared to accurately represent the degraded soil areas in the hilly land and the degraded sandy soils on the high terraces, but not in the agricultural lowland, because on hilly and sandy terraces soil organic matter and soil moisture content were very low. The study shows that satellite imagery is a very useful tool for soil degradation studies.

# 1. Introduction

Deforestation, desertification and land degradation have been critical global environmental issues during the past decade. Monitoring of cover conditions and their changes is essential to the identification of environmental problems at both the local and global scale (Oldeman, 1994).

Vietnam, with a population of 77 million, covers a total land area of 33,104 Mha (Nhuan,

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1996), of which three fourths consists of high steep mountains with a complex topography. Forest cover in 1945 was 19 Mha, gradually declining to 9.3 Mha in 1992 (Phong, 1995). Non-cultivated land comprised 13 Mha up to 1995, including 10.4 Mha bare land, distributed over 56 soil units of 12 soil groups, including ferralsols (65%), high mountain humus soils (12.6%), eroded land with partial rock outcrops (8.6%) and others (13.8%). A total of 5.5 Mha are strongly degraded. 4.6 Mha intermediately and 4.6 Mha slightly (Siem and Phien, 1999). It is, therefore, important to monitor land and water management practices causing severe soil degradation. Remote sensing is one of the key tools in monitoring local, regional and global environmental issues. Recently, attention has been paid to spatial analysis via combinations of Geographic Information Systems (GIS) and satellite images for environmental research and applications (Hill and Schütt, 2000; Harahsheh and Tateishi, 2000; Harmsen, 2004). Examples of such studies are that of Tateishi (2003) for soil degradation, which yielded essential information for management of natural resources, that of Gad (2002) for obtaining land use and land cover maps on the basis of 132 field observations and 65 soil profiles to arrive at a map of soil degradation, and that of Zeleke and Hurni (2001), indicating the increase in soil degradation in Dembecha, Gojam, Ethiopia with declining cover of natural forest from 27% in 1957 via 2% in 1982 to 0.3% in 1995. At more detailed level, Huete et al. (2002) combined EO-1 and air-born AVIRIS with field measurements of an ASD spectroradiometer to identify types and stages of soil degradation. Nizeyimana and Petersen (1998) distinguished different soil erosion classes using the Bright Index (BI) derived from multi-spectral spot images. In the present paper, a study is described in which multi-temporal LANDSAT digital data are used in combination with ground truth data to study land use dynamics and soil degradation in Tamduong, an upstream district in the Red River Delta in the north of Vietnam.

## 2. Methodology

#### 2.1 Study Area

Tamduong district in Vietnam is located upstream in the Red River Basin (21°18' to 21°27'N, 105°36' to 105°38'E), about 60 km northeast of Hanoi, in the transitional zone between almost flat lowlands and the mountainous regions (Figure 1). The flat southern part (3 communes) is characterized by paddy rice and vegetable cropping systems; the middle part (7 communes) consists of alternating flat and hilly land at altitudes between 20 and 100 m above sea level (asl). More than half of the district (7 communes in the Northern part) is mountainous along the Tamdao range from northwest to southeast, at altitudes ranging



Figure 1: Location of (left) Red River Delta, (center) provinces in the Delta and Tamduong district and (right) its sub-division into 7 mountainous communes (dark-grey), 7 midland communes (grey) and 3 flat lowland communes (white)

from 100 to 1400 m asl. The district has a total area of 19,779 ha, with 7,838 ha of agricultural land (including 6,147 ha of annual crops and 1,691 ha of perennial crops), 6,744 ha of forest, while the remainder is non-cultivated land. Seven soil types were distinguished: Acrisols, Cambisols, Gleysols, Fluvisols, Plinthosols, Arenosols and Leptosols.

## 2.2 Methodology

The data used in this study are one LANDSAT-MSS image (MSS84) operating in 4 bands with 80 m spatial resolution acquired on 8<sup>th</sup> May 1984 and four LANDSAT-TM images operating in 6 bands with 30 m spatial resolution acquired on 21st October 1992, 18th October 1996 and 11th April 2000 (TM92, TM96 and TM00). Although the images are acquired at difference dates, the land cover status is quite similar, because October is early and April late dry season, both with low land cover, and May early rainy season, when biomass is still very low, as is soil water content. Colour Composites (CC) were generated using band combinations of red, green and blue (RGB) of 4:3:2 for the MSS84 image and of 5:4:3 for the TM92, TM96 and TM00 images for visual interpretation of temporal changes in land use and land cover. Use of band ratios (BRs), generated by dividing the pixels in one band by the corresponding pixels in a second band, to suppress illumination differences attributable to surface albedo, incidence angle and topographic effects, has a long history of successful applications to multispectral data. In this study, two types of BR are generated by dividing the Red band by the Green band (ratio = R/G) and dividing the Red band by the Near Infrared band (ratio = R/NIR). The band ratio R/NIR is the inverse of the Ratio Vegetation Index (RVI), that has been widely and successfully used to map and/or monitor vegetation (Gilabert et al., 2002). The TM00 image was supervised classified to differentiate degraded soil from forest and arable soils and other land use types. The classified map was adjusted to match reality by comparison with the map of degraded soils derived from the

district soil map (Khang et al., 1998) and field checks. The band ratio giving the best fit with ground truth data is selected for further work. Soil degradation was deduced from the supervised classified map of selected BRs at each date, combined with the RGB colour combinations to simulate land use dynamics and changes in soil degradation in the study area.

## 3. Results and Discussion

#### 3.1 Image Preprocessing

Before performing digital processing, all images were radiometrically normalized. To compensate for variations in the sensor radiometric responses over time and for variations in natural conditions of solar irradiance and solar angles, digital numbers were first converted into exo-atmosphere reflectance values (Markham and Barker, 1985) and radiometrically corrected (Hall et al., 1991) by applying the minimum substraction method (Chavez, 1988) to remove the effect of haze. After radiometric normalization, images were geometrically corrected. The TM00 image was converted to the UTM coordinate system, using common control points extracted from a topographic map at the scale of 1:50,000. Using a first-degree polynomial rectification algorithm, this procedure yielded a registration accuracy equal to 0.8 pixel. Following this procedure, the other images were registered through an image-to-image tie-down algorithm using ILWIS 3.0 for Windows.

#### 3.2 Image Processing and Band Ratio Selection

There are two reasons for using BR (Abdeen et al., 2001; Penn, 2002, Ren and Abdelsalam, 2003; Higgs, 2004): (i) differences between the spectral reflectance curves of surface types can be brought out, (ii) illumination, and consequently radiance, may vary, but the ratio between an illuminated and a non-illuminated area of the same surface type will be the same. Based on this principle, vegetated soil and bare/degraded soil can be differentiated by using the band ratios. For the R/G ratio, bare and degraded soils show high reflectance in the red band but low in the

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green one, while vegetated soils show lower reflectance in the red band. Hence, the ratio R/G will give high values for bare/degraded soils and low for vegetated areas. As for the ratio R/ NIR, features such as water reflect strongly in the R band and weakly in the NIR band, roads slightly stronger in the R band than in the NIR band, while features such as vegetation show relatively low reflectance in the R band and high reflectance in the NIR band (Lillesand and Kiefer, 1994). Therefore, the ratio R/NIR gives high values for water and bare soils and low values for vegetation (Figure 2).

On both BR images (Figure 2), natural forest (low values, blue color) and bare/degraded soils (high values, red color) can easily be distinguished visually. But the difference between the two ratios is that in the R/G image the values for degraded soil and village and for planted forest and agriculture land are very close, while these features can be distinguished in the R/NIR image with strong red colors for water, light blue for agricultural land, green orange for planted forest and red orange for villages. This results in four classes in the classified map of BR R/G and in 6 classes in BR R/NIR, while recognizably maintaining the geometric features. In addition, BR R/NIR shows distinctly different values for different features; therefore slicing classified (Figure 2(e)) works well with this BR and gives comparable results to the supervised classified map (Figure 2(f)). Based on all these advantages, the band ratio R/NIR is used for further image processing and classification.

### 3.3 Soil Degradation

The soil degradation map for the area was derived from the soil map (Khang et al., 1998) in combination with field checks for each soil unit, based on the guidelines of Oldeman (1994) where soil degradation was classified into different types, causes, degrees, rates and extent. The dominant degradation process in the area is water erosion, caused by forest cutting, agricultural land use on sloping land with very low or no fertilizer input and without soil conservation measures. Soils are mostly sandy, with very low organic carbon, and nutrient contents as well as Cation Exchange Capacity. Thu et al. (1997) found a wide range in soil erosion rates for different types of land cover in upland soils with slopes from 5 to 8 degrees in three years in Tamduong with an annual rainfall exceeding 2000 mm (Table 1).

Soil erosion rate was very high on bare soil, eucalyptus forest and agricultural land. Not only surface soil was removed, but also many nutrients were lost, as in the experiment carried out by Toan et al. (1998) from 1992 to 1996 at another site within the same district, with rainfall varying from 800 to 1890 mm yr<sup>-1</sup>. In that experiment, soil loss, runoff and nutrient loss have been measured and the results showed soil nutrient losses on bare soil of 599.2 kg ha<sup>-1</sup> yr<sup>-1</sup> of organic carbon, 52 kg nitrogen, 26.6 kg phosphorus and 34.6 kg potassium and on cassava 295, 28.3, 21.3 and 22.4 kg, respectively.

## 3.4. Field Observations

For each of twenty one ground truth points we determined type, state and degree of degradation and the results showed satisfactory agreement with the classified map (R/NIR band ratio), with 9 strongly degraded observations, on bare soil, poor eucalyptus plantations and sandy soil on terraces. Three points on upland soil with cassava and fruit tree plantations showed intermediate levels of soil degradation, while only two were part of the degraded domain on the classified map.

The classified map was compared to the soil degradation map derived from the soil map and ground truth data, showing that most land classified as degraded on the classified map was located in the degraded domain of the soil degradation map, but not all. The reason is that on the classified map the most strongly degraded soils were identified where soils were dry, with low organic matter content, high sand content and poor land cover. However, as explained before, part of the degraded land has been reclaimed through reforestation, high organic matter applications to crops or through planting of productive fruit trees, with high land



0.98 0.87 0.77

5000 m

Natural Forest Planted Forest Agriculture Village degradedsoil (c)

(f

(b)

(e)



Land cover	Soil erosion rate (ton ha <sup>-1</sup> year <sup>-1</sup> )
Bare soil	189.4
Eight-year old Acacia mungium forest	34.8
Ten-year old regenerated mixed forest	38.9
Pineapple	85.2
Eucalyptus forest	158.8
Agroforestry (less than 3 years olds, 8 degree slope)	75.0
Agroforestry (after 3 years, 19 degrees slope)	93.0

Table 1: Soil erosion rate for different land covers in Tamduc	ng
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Source: Thu et al. (1997)

(d

cover and biomass. In other words, degraded sandy soils located on terraces are being cultivated, and their reflectance is thus reduced, as they are covered by crops, such as beans and rice.

#### 3.5. Soil Degradation Dynamics

For classification, degraded land was identified by classifying the BR red/near-infrared for all dates in 1984, 1992, 1996 and 2000. The results (Figure 3) yielded clear pictures of soil degradation dynamics since 1984. The extent of soil degradation in Tamduong fluctuated from 2440 ha in 1984 via 3280 ha in 1992 to 2190 ha in 1996 and 2580 ha in 2000. This trend is realistic and can be associated with human activities in Tamduong district: when forest was cut, soil degradation started and aggravated till 1992. During the years 1990-1992, large-scale reforestation took place (mostly Eucalyptus for supply to the paper mill), with the associated higher land cover and biomass, reducing erosion and soil degradation. The productive forest has been harvested since 1996, resulting in larger bare soil areas and increased soil degradation.

## 4. Conclusion

The band ratio red/near-infrared gave better result than the band ratio red/green, because it showed different value ranges for different land use types. Color Composite and supervised classified images of the red/near-infrared band ratio showed that in Tamduong district in Vietnam, most degraded soils, especially the strongly degraded and bare soils, with very high reflectance and distinct colours, are located on the hilly land and on high-level sandy terraces. Classified images from 1984, 1992, 1996 and 2000 clearly show the trends in the extent of soil degradation with 2440 ha in 1984, 3280 ha in 1992, 2190 ha in 1996 and 2580 ha in 2000, a trend that is closely related to land use dynamics in the district, especially the forest cover and agricultural activities in the upland soils. These results illustrate the possibilities for use of satellite images for identification of degraded soils. Moreover, types, causes and degrees of soil degradation could possibly be identified by testing more satellite images with different resolution and functions in combination with more ground truth data, including detailed soil properties.



Figure 3: Classified maps derived from band ratio R/NIR in 1984, 1992 and 2000 in Tamduong

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