Use of Landsat TM and DEM Data in Producing Reconnaissance Scale Soil Maps.

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Abstract

Soil maps, even small scale ones, are often too expensive and too time consuming to perform, especially in research programs, when a general overview on natural resources is needed.

In a Pliocene clays area in Southern Tuscany (Italy), the National Research Council (C.N.R.) Centre for Soil Genesis, Classification and Cartography has being studying for several years soil degradation processes involved in badlands evolution in some experimental plots. A soil-landscape map was so necessary for extending experimental data to a larger and more representative area. A 236 km² area was chosen for producing a 1:50,000 soil map, based on Landsat TM and digital elevation model data.

The area comprises part of the upper and middle Orcia Valley, a neogenic basin filled in with marine sediments during Pliocene. The deposits are mainly clays and silty clays, while other lithologies are present along the border of the basin and along the rivers (alluvial deposits). The altitude varies from 250 to 900 m a.s.l. Climate is intermediate between Mediterranean and continental. The whole basin is characterised by an intense morphodynamic due to several factors, mainly neotectonics, climate and lithology, acting synergically to delineate the landscape. The result of the morphodynamics is a landscape subject to frequent and recurrent mass movements and water erosional forms. Among the latter, badlands known as *calanchi* and *biancane* are the most typical of the area. On Pliocene clays arable lands are predominant, while vineyards and olive groves, and woodlands are present on steeper zones.

As the research was carried out on clays, and as geomorphology seems to have an extremely important role on soil genesis, an approach based on integrated use of Landsat TM and DEM data was tested. Land units were obtained by a previous masking of lithologies other than clays, and by integrating information on slope, aspect, greenness and brightness. A program for filtering redundancy in information was created and applied.

Land units so obtained were controlled in the field and soil profiles were collected and described. Resulting soil-landscape map has been controlled with previous and undergoing surveys and a discussion on results is presented.

Résumé

Les cartes pédologiques sont fréquemment très laborieuses et coûteuses à réaliser, en particulier dans le cas d'un projet de recherche, quand est nécessaire une description des ressources naturelles.

Le présent travail a été réalisé dans le cadre d'un projet de recherche du Conseil National de la Recherche d'Italie (CNR) concernant l'étude de la dégradation des sols dans une zone de la Toscane (Italie) ayant une lithologie du type Pliocène argileux.

La zone d'étude (approx. 236 km²) est caractérisée par des formes d'érosion localement connues comme *biancane* et *calanchi*. La zone, située dans le haut et moyen bassin du fleuve Orcia, est caractérisée par une intense activité morphodynamique liée à la tectonique, au climat et à la lithologie.

La recherche a été conduite sur les dépôts argileux; où la morphologie joue un rôle très important dans la formation des sols.

Avec l'intégration des différents types de données dans un Système d'Informations Géographiques (cartes géologiques, images satellitaires Landsat TM, modèle numérique de terrain), il a eté dressé une carte des sols-paysages (échelle 1/50 000).

Dans une deuxième phase la carte a eté contrôlée sur le terrain avec des sondages à la tarière et avec la description et l'échantillonnage des profils pédologiques.

Enfin la carte a été contrôlée avec une carte des Systèmes des Terres réalisée par une autre équipe du CNR dans la même zone.

Introduction

In a Pliocene marine clays deposit area, located in southern Tuscany (Italy), C.N.R. Soil Genesis, Classification and Cartography Study Centre of Florence has been involved in a research on soil degradation problems linked to erosion and badlands generation, for several years. Soil erosion and degradation processes have been studied and their correlation with main morphological, vegetational, pedological, climatological feature have been investigated in order to perform a model for badlands evolution comprehension. Several experimental plots have been established and very detailed studies have been performed (SORIANO *et al.*, 1992; CALZOLARI *et al.*, 1993; COLICA, 1993; CALZOLARI *et al.*, in press; CHIARUCCI *et al.*, in press; TORRI *et al.*, in press).

In order to generalise experimental results to wider areas, a soil-landscape map at a reconnaissance scale, basin level, was necessary. Due to high cost and to time consuming procedures involved in a soil map production, a speditive way to map landscape was studied.

Utilisation of satellite data in soil mapping is well known in literature, where some interesting examples, especially in recent years, are found (WESTIN and FRAZEE, 1976; ROUDABUSH *et al.*, 1985; FRAZIER and CHENG, 1989; HINSE *et al.*, 1990; AGBU and NIZEYIMANA, 1991).

Soil is a complex three dimensional system, at the interface of living organisms and inorganic matter, with a solid, a liquid and a gaseous phases. This complexity has an influence on reflectance characteristics of terrain and represents an additional difficulty for the use of satellite data in soil survey and mapping. In fact, unlike as in land form or land cover interpretation, the interpreter cannot "see" soils on satellite images. Usually, in satellite images, the interpreter can only infer information about soils from other evidences such as land form (ABDEL-HADY *et al.*, 1991), land cover (THOMPSON *et al.*, 1984; SAMSON and LEWIS, 1991) or both of them (LEWIS *et al.*, 1975); another possibility is to use remote sensing data in conjunction with other kind of data like digital elevation models or other geostatistical data, in geographic information systems (HORVATH *et al.*, 1987; LEE *et al.*, 1988; SU *et al.*, 1990; BHATTI *et al.*, 1991; DUBUQ *et al.*, 1991).

Most of the information about spectral characteristic of soils derives from field or laboratory experiments, conducted under controlled environmental conditions with radiometers operating in different wavelengths (CIPRA *et al.*, 1980; WRIGHT and BIRNIE, 1986; PRICE, 1990). Speaking of "commercial data", produced by earth resources satellites, up to date only a limited amount of soil surface characteristics are known to have a certain influence on soil spectral signature. They are (THOMPSON *et al.*, 1983; BAUMGARDNER *et al.*, 1985; MULDERS, 1987; ESCADAFAL *et al.*, 1989; AGBU *et al.*, 1990; GIORDANO, 1991): colour, particle size (especially clay content), organic matter, moisture content, iron oxides, surface roughness.

These characteristics influence soil reflectance in the same measure in different wavelengths, thus diminishing the information value of satellite bands combinations (colour composites, classifications, ratios, etc.), that have had great success in vegetation or land cover studies. Another limitation is that quite often, particularly at mid latitudes, soils are vegetated for great part, when not for all, of the year. There are also other difficulties, in common with other remote sensing applications, like atmospheric filter, cloud cover, etc. Last but not least the fact that spatial variability of soils occur at a much larger scale then the capabilities of satellite images must be taken into account.

Digital satellite images can either be processed in order to improve their interpretability, or be classified to produce maps. Different elaborations for soil mapping have been tested such as: rationing of bands (FRAZIER and CHENG, 1989; AGBU *et al.*, 1990); transformations like brightness (LEE *et al.*, 1988; BUTTNER and CSILLAG, 1989; AGBU *et al.*, 1990) or principal component analysis (LEE *et al.*, 1988; CALZOLARI and SARFATTI, 1994); vegetation indexes (BUTTNER and CSILLAG, 1990); classifications (KORNBLAU and CIPRA, 1983).

In the present paper a case study is presented about the integrated use of Landsat TM data, with brightness and greenness indexes, and DEM data, slope and aspect, in producing a semi-automatic soil-landscape preliminary map, at a 1:50,000 scale, for field control.

Study Area

The study area is located in Southern Tuscany and is delimited between 42°56' N and 43°4' N latitude and between 11°37' E and 11°48' E longitude, including a total surface of approximately 236 km^2.

The area comprises a large part of upper and middle Orcia basin, a neogenic basin filled during Pliocene with marine sediments (IACOBACCI *et al.*, 1967). Deposits are mainly clays and silty clays, while sands, conglomerates and organogenous limes are found along the border of the basin. The underlying deposits of the Allochthonous and Autochthonous Tuscan formation (CASTELVECCHI and VITTORINI, 1967) outcrop somewhere at the edges of the basin. Quaternary alluvial terraced deposits are found along the rivers and volcanic deposits of Mount Amiata are present in the south western zone of the area. Pliocene clays are characterized by typical erosion forms (badlands), locally called *biancane* and *calanchi.*

The main streams of the area are the Orcia river and its tributary, the Formone river.

The altitude varies from 250 m, in the lower valley, to 900 m a.s.l. of the surrounding mountains; land form is almost flat on fluvial terraces and alluvial plains, gently hilly in the centre, where clay is predominant, steeper in the southern part of the study area and on the mountains.

The climate is intermediate between Mediterranean and continental, with dry hot summers, cool winters and two humid periods during fall and springs, temperature and precipitation are correlated with altitude.

On Pliocene clays arable lands are predominant, and crops like winter wheat and winter barley are the most common. Permanent pastures are common on badlands. Irrigated crops, like maize, are found on alluvial plains. Woodlands are present on steeper slopes, while vineyards and olive groves, usually inter cropped with arable, are found on hilly Pliocene sands and conglomerates, and on shales of Allocthonous Complex. Natural vegetation is confined on badlands areas and along rivers and streams. Badlands vegetation is very characteristics and mostly influenced by the degree of degradation processes. The most degraded zones lack even herbaceous vegetation. At the first stages of colonisation, vegetation is characterised by a scanty herbaceous cover of pioneer, myoalophytes species, typical of *Parapholido- Artemisietum cretaceae* formation (CHIARUCCI *et al.*, in press).

On more stable morphologies other formations can be found, related to specific soil and micro climate conditions. The most common formation is *Brometum* grassland, with or without *Spartium junceum* shrubs, which is the most evolved grassland under xeric conditions.

Spots of structured shrubs with Ligustrum vulgare, Rosa agrestis, Crataegus monogyna, Juniperus communis, Ulmus minor and Quercus pubescens, can be found, in those areas less disturbed by erosion and by man.

Research concerns soils developed on Pliocene clays. In these soils (CALZOLARI et al., 1989, CALZOLARI et al. 1993, LULLI et al., 1980) given the peculiar characteristics of parent material, climate and morphology, pedogenesis is fairly superficial and characterised by physical rather than chemical processes. Processes are largely conditioned by erosion which continuously renews profile. Nevertheless, with fairly good internal drainage, under a sufficient vegetation cover, on relatively stable morphologies a certain degree of pedogenesis is possible, along well defined evolution trends, strictly linked to geomorphological dynamics.

Pliocene clays are a relatively homogeneous parent material (COLICA, 1993.), macroclimate can be considered roughly not influent in pedogenetic processes, due to the fact that Pliocene clays are situated in the centre of the basin where the altitudes range and climatic excursion are modest (COLICA, 1993) so that morphology, as affecting soil erosion and slopes dynamics, land cover and aspect, as influencing microclimatic characteristics of the soils, seem to be the most important factors in pedogenesis.

Materials and methods

The work has been conducted through the following steps (a diagram flow is illustrated in figure 1).

Input of data into a Geographical Information System.

Geological data have been digitised from a geological map (IACOBACCI *et al.*, 1967), scale 1:100,000. Vectors have been converted to raster with a grid of 30*30 m of resolution.

Elevation data have been obtained digitising the contour lines (equidistance 25 m) from a topographic map, scale 1:25,000. A digital elevation model with a grid of 30 by 30 m have been calculated and aspect (expressed in °N) and slope (expressed in %), for each cell, have been derived.

Satellite data (a Landsat TM subscene of 512 x 512 pixels, ground resolution of 30 m, path 192, row 30, acquisition September 1987) have been geometrically corrected to UTM map projection, using a third order polynomial and a nearest neighbour resampling algorithm. After georeferencing the TM bands have been transformed using the Tasseled Cap transformation, deriving Brightness and Greenness.

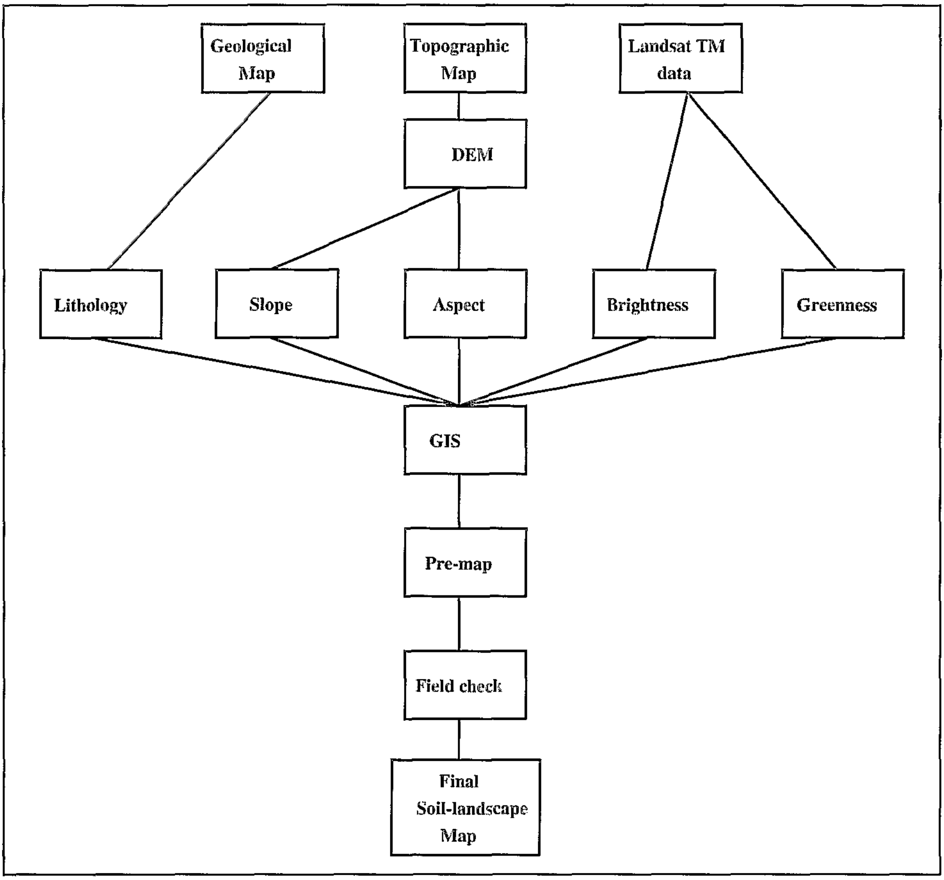

Figure 1. Flow diagram of the methodology adopted.

GIS processing

Each raster information layer has been segmented into two classes as in following scheme:

Layer	Class 1	Class 2
Lithology	Pliocene	Other Lithologies
Aspect	North	South
Slope	Flat/ Rolling	Sloping
Brightness	Dark Soils	Bright Soils
Greenness	Vegetated	Not Vegetated

Threshold values have been chosen according to empirical criteria: brightness and greenness values have been chosen on the base of visual interpretation of resulting images; slope of 5% is the limit between flat and rolling morphologies and sloping ones; only two classes for aspect have been chosen, corresponding to north facing (270°-90° N), and south facing slopes (90°-270° N).

The area has been classified crossing each information layer with the remainders. Only Pliocene clays pixels have been classified. For the vegetated pixels it has not been taken into account the information relative to the soil brightness.

The resulting legend comprehends the 12 classes derived from the overlaying and one class for the other lithologies:

1.	Slope =< 5%	South facing	Dark	Not vegetated
2.	Slope > 5%	South facing	Dark	Not vegetated
3.	slope =< 5%	North facing	Dark	Not vegetated
4.	slope > 5%	North facing	Dark	Not vegetated
5.	slope =< 5%	South facing	Bright	Not vegetated
6.	slope > 5%	South facing	Bright	Not vegetated
7.	slope =< 5%	North facing	Bright	Not vegetated
8.	slope > 5%	North facing	Bright	Not vegetated
9.	slope =< 5%	South facing	Vegetated	
10.	slope > 5%	South facing	Vegetated	
11.	slope =< 5%	North facing	Vegetated	
12.	slope > 5%	North facing	Vegetated	
13.	Other lithologies			

Filtering of the classified (raster) data

The use of the overlaying technique integrating remotely-sensed data produced a salt-and-pepper appearance of the classified image, which consisted of 9,671 polygons.

A map derived from such an image can be difficult to read, to field check and to incorporate into a GIS (TROTTER, 1991). In order to overcome such a difficulty a simple three-step process which outputs a derived classification where the minimum polygon size can be an user's input, has been performed. In fact from a cartographic point of view, a representation of too small areas is not correct: as an extreme, a single Landsat TM pixel at the scale of 1:100,000 approximates the limit of the human eye's capability of distinguish an area from a point, i.e. from a dimensionless object on the map.

In our approach in the first step a logical smoothing has been performed, using a 3x3 box; local frequencies have been calculated for the values of the pixels connected to the centre pixel, to which has then been assigned the modal value: in this way, its connectedness has been assured. During this first step, a strong reduction in the overall number of polygons has been achieved, mainly due to isolated pixel suppression; polygon borders have also been "smoothed." This process, similar to the one described by TOWNSEND (1986), has been performed sequentially (in Townsend's acception), but in a pseudo-random way: odd pixels of odd rows have been scanned from top left to bottom right, even pixels of odd rows from top right to bottom left, even pixels of even rows from bottom right to top left and odd pixels of even rows from bottom left to top right, to reduce computation time while minimising the negative effects described by Townsend.

In the second step, all remaining polygons whose area is less then a user-specified threshold, without regarding to the polygon shape, have been recognised and their class value has been replaced with a marker, i.e. a value which was not present in the original classification.

In the third step, a 5x5 box performing a logical smoothing as in the first step has been applied only to marked pixels; the image has been scanned from top to bottom, odd rows from left to right, even rows from right to left. The effect has been an "invasion" of marked polygons by all the neighbouring, not only from the dominant one (as in DAVIS and PEET, 1976), with no effect on the remainder of the image.

The algorithm has been evaluated to produce a map at scale 1:50,000, with twelve different minimum map area threshold levels, from 4 pixels, corresponding to a map area of 1.44 mm^2, up to 48, corresponding to 17.28 mm^2. For each run of the procedure the number of resulting polygons has been recorded; also, resulting classification has been compared with the original on a pixel-per-pixel basis, producing an error matrix to evaluate accuracy; for each matrix, an overall accuracy coefficient has been calculated, and the percentage of commission error for each resulting class: this last figure is the most significant from a user's point of view, as they account for the reliability of the map (STORY and CONGALTON, 1986).

After filtering, raster data have been converted into staircase-like vector polygons and a preliminary map has been plotted at 1:25,000 scale.

Field check and laboratory analyses

The map has been controlled with 180 field observations (auger hole), some of which have been discarded, distributed as in Table 1. The areas of the control points of the observations have been chosen *a priori* on a draft copy of the map, so to assure to cover all the most represented delineation of each unit. The exact point for the core description has been chosen in field, depending on the representatives of the situation. A complete representative soil profile has been described (according to SANESI, 1977) and sampled, for each mapping unit, for a total number of 14 profiles.

Table 1. Number of observations for each mapping unit.

Mapping Units	Total area (ha)	N° of observations
1	1,384	24
2	563	12
3	2,338	21
4	1,129	13
5	2,639	19
6	1,966	18
7	1,582	15
8	821	12
9	253	8
10	649	7
11	559	12
12	970	8
Total		**169**

Samples have been analysed in laboratory and texture, OM, pH, total $CaCO_3$, EC 1:5 have been determined (as in SISS, 1992).

Ground check of the final map and comparison with a Land System map of the area.

In order to evaluate in a semi-quantitative way the reliability of the map, confidence tables for some of the characteristics considered, against field control points, have been produced. Characteristics that have been controlled are: slope, aspect, vegetation cover. Brightness and greenness have been considered "objective" data, while a general lithological control has been necessary for the whole area.

A further control of the results has been performed comparing the map with a land system map prepared meanwhile by other components of the research team (BUSONI *et al.*, in press).

For this control the original 14 classes of our map, and the 19 classes of the land system map, have been reduced to 7, to uniform the criteria, leaving only geomorphological assumes in both the maps, as explained in table 2.

Table 2. Correspondence table between Soil-landscape and Land System mapping units.

	Soil-landscape map	Land System map
1	13	Other lithologies units (3,4b,5,6,13,14,19)
2	14	Terraced Units (3i, 3t)
3	3-7	Slope Units (1)
4	1-5	Slope Units (2, 10, 16)
5	9-10-11-12	Slope Units (7a,12)
6	2-6	Slope Units (8, 9)
7	4-8	Slope Units (4a, 7b, 11, 15, 17)

For the accuracy estimate of the map 400 points have been controlled, through a 20*20 grid, expecting an accuracy of 70% and a maximum error of the estimate of 20% (according to SNEDECOR and COCHRAN, 1980). An error matrix has been done and the "index of agreement" of COHEN (1960) (as in ALESSANDRO and BAGNOLI, 1990) has been calculated for the whole matrix, K, and for each mapping unit, K_i (BISHOP, 1975), according to the formulas:

$$K = \frac{Q_1 - Q_2}{1 - Q_2} \text{ and } K_i = \frac{N \cdot n_{ii} - n_{i+} \cdot n_{+i}}{N \cdot n_{i+} - n_{i+} \cdot n_{+i}} \qquad Q_2 = \sum_{i=1}^{r} \frac{n_{i+} \cdot n_{+i}}{N^2}$$

where :

r = total number of rows and columns of the matrix;
n_{ii} = number of observation along the diagonal of the matrix;
n_{i+} = number of observation along the row;
n_{+i} = number of observation along the column;
N = total number of observations.

Correction of the preliminary map

On the basis of field controls, laboratory analyses and after a photo-interpretation control, draft map has been corrected, excluding not Pliocene clays zones detected on field, incorrect on original geological maps, and separating alluvial upper terraces from actual flood plains and river beds.

A final "soil-landscape" map has been prepared with the original 13 classes legend enriched with one more class, alluvial terraces, and with soil characteristics, and their variability (semi-quantitative estimate).

Results and discussion

A 14 mapping unit soil-landscape map has been produced (Fig. 2). The results of smoothing process are shown in table 3. The number of polygons drops from 9,671 in the original image to 2,185 simply imposing a minimal area of 4 pixels. In fact, most of the original polygons were just isolated pixels or small groups of two or three.

Table 3 shows the correlation existing between minimal area, polygon number and map accuracy; while map accuracy decreases linearly for increasing minimal areas, the reduction in the overall polygon number is higher for smaller minimal areas, lowering as the minimal area increase, thus following an inverse linear model. In our example, a threshold of 28 pixels (corresponding to a unit of 2.52 ha, or 10 mm^2 on the map at the scale 1:50,000) it has been used. Resulting map contains 1,006 polygons, only 10.4% of the polygons that were present in the original classification, with a total commission error of 20% (Table 4).

Table 3. Number of resulting polygons and map accuracy for different minimal area thresholds.

Minimum map unit (in pixel)	N° of polygons	Overall accuracy (%)
4	2185	**.88**
8	1802	**.868**
12	1546	**.855**
16	1377	**.843**
20	1228	**.829**
24	1115	**.816**
28	1006	**.801**
32	937	**.790**
36	886	**.781**
40	828	**.77**
44	772	**.759**
48	717	**.746**

Table 4: Matrix of classes distribution (%) after post-classification filtering, with a threshold minimal area of 28 pixels. Rows: the original classes. Columns: classes after filtering.

Class	1	2	3	4	5	6	7	8	9	10	11	12
1	80.6	1.2	2.5	0.3	9.3	0.6	0.9	0.2	2.6	0.4	0.9	0.4
2	2.1	79.4	0.1	0.8	0.9	8.8	0.2	0.1	0.4	7	0.0	0.2
3	2.2	0.0	83.7	0.7	0.6	0.0	8.5	0.3	0.4	0.1	3.3	0.1
4	0.4	1.1	2.7	77.3	0.2	0.3	0.7	8.9	0.0	0.4	0.7	7.2
5	9.3	0.4	0.7	0.0	82.1	0.9	2.6	0.1	3.2	0.2	0.5	0.0
6	1.3	8.2	0.1	0.3	3.3	77.7	0.5	1.0	0.8	6.4	0.2	0.3
7	0.6	0.1	8.9	0.4	1.4	0.1	82.3	1.0	0.3	0.0	4.5	0.4
8	0.1	0.2	1.1	9.0	0.1	1.1	3.0	77.8	0.1	0.3	0.9	6.2
9	7.9	0.4	0.6	0.0	8.4	1.2	0.8	0.0	75.4	2.0	3.4	0.0
10	0.6	8.3	0.5	0.2	0.8	8.5	0.3	0.3	3.2	75.7	0.5	1.0
11	1.3	0.2	8.0	0.7	0.7	0.1	9.1	0.7	3.1	0.1	73.3	2.6
12	0.2	0.5	1.0	7.5	0.0	0.3	0.8	5.1	0.3	0.9	3.2	80.2

The legend of the mapping units comprehends a description of the morphology of land use and vegetation, of principal soils and their variability, and a soil profile description and analyses. An example of mapping unit descriptions is reported in table 5.

In order to evaluate in a semi-quantitative way the reliability of the map, confidence Tables for some of the characteristics considered, against field control points, have been produced. Characteristics that have been controlled are: slope, aspect, vegetation cover. Brightness and greenness have been considered "objective" data, while a general lithological control has been necessary for the whole area.

Results of the analysis are reported in table 6. As it can be noted the confidence level for land cover and aspect is high, while is around 60% for slopes. This can be explained with the use of very broad classes, due to the scale of the survey, as compared to the punctual definition of slope class in field survey. Besides this, it must be stressed that the confidence values are very high in some units that are very homogeneous, while is lower in some, more complex units.

Table 5. Mapping Unit description (example extract).

Mapping Unit 1	Slope< 5%, North facing, dark, not vegetated
Morphology	Rolling, short slopes.
Slope angle	< 5%
Stoniness	Absent
Land use	Cropping, winter durum wheat, barley
Soil	*Typic Xerorthents*, fine, mixed (calcareous), mesic. (profiles 1005, 1004)
Variability within the mapping unit	
Land use	Cropping 67%; pastures 33%
Moisture regime	Xeric 80%, Ustic 20%
Slope angle	2-15%
Soils	*Typic Xerorthents* 80%; Typic and Vertic Ustorthents 20%.Inclusions Vertisols

Table 6. Confidence of slope, aspect and vegetation estimates after field check. Unit purity expresses the percentage of pixels of the original class after filtering of classified data, as in table 4.

Mapping Unit	Unit Purity (%)	Confidence **Slope** (%)	Confidence **Aspect** (%)	Confidence **Land Cover** (%)
1 slope <=5%, south, dark, not vegetated	80.6	75.0	58.3	100.0
2 slope >5%, south, dark, not vegetated	79.4	17.4	66.7	77.8
3 slope <=5%, north, dark, not vegetated	83.7	76.2	71.4	94.4
4 slope >5%, north, dark, not vegetated	77.3	84.6	80.0	88.9
5 slope<=5%, south, bright, not vegetated	82.1	61.1	73.7	94.4
6 slope >5%, south, bright, not vegetated	77.7	66.7	76.9	92.9
7 slope<=5%, north, bright, not vegetated	82.3	71.4	64.3	83.3
8 slope >5%, north, bright, not vegetated	77.8	58.3	70.0	88.9
9 slope <=5%, south, vegetated	75.4	37.5	85.7	75.0
10 slope >5%, south, vegetated	75.7	42.8	83.3	42.8
11 slope <=5%, north, vegetated	73.3	54.5	90.9	70.0
12 slope >5%, north, vegetated	80.2	50.0	40.0	62.5
Mean values	78.79	57.96	71.77	80.91

A further control has been done with a Land System map of the area (BUSONI *et al.*, in press) after the described correlation among the mapping units and consequent reduction to 7 mapping units. The error matrix, table 7, with the values of K and K_i and K_{glob} (i.e. global accuracy of the map, given by the ratio between the number of the points on the diagonal and the total number of control points), has been obtained, as already pointed out, assuming the land system map as "ground truth".

The K values resulting are around 50%, and they largely vary with the different land units. They are higher in mapping units like "other lithologies" and "terraced alluvial plains," medium in lithologically homogeneous areas, and lower in very complex (lithologically and morphologically) units. It must be stressed that the assumes of the two maps are fairly different, as the soil-landscape map represents units homogeneous for slope, aspect, lithology and land cover, while in the Land System map, length and complexity of slopes, symmetry, hydrographic network, and so on, are evidenced.

Table 7. Error matrix and K values of the map against land system map. Rows: Cartographic units of the Soil-Landscape map. Columns: Cartographic units of the Land System map.

Mapping Units	1a	2a	3a	4a	5a	6a	7a	Total	K_i
1b	121	6	2	20	0	7	11	167	0.589
2b	3	8	1	0	0	0	0	12	0.652
3b	0	1	22	27	0	0	6	56	0.344
4b	2	1	5	47	0	6	8	69	0.553
5b	1	1	0	9	8	3	13	35	0.207
6b	0	0	0	6	0	10	15	31	0.274
7b	5	0	0	6	3	1	15	30	0.398
Total	132	17	30	115	11	27	68	400	

Conclusions

Several conclusion can be drawn by our study.

The first one concerns the smoothing process. The raster classification derived from it has been simply converted into staircase-like vector polygons; sophisticated raster-to-vector conversions have been discarded, to avoid introduction of another source of error (MAFFINI, 1897). This produced a map with staircase lines, when produced automatically, and with straight lines in the manually corrected areas. An increase in processing times in the GIS has been noticed using staircase vs. smoothed lines, but it was not significant from an operational point of view.

As concerns the reliability of the map this can be considered satisfying. A high correspondence between the classification and ground control points has been detected. The comparison between the pedo-landscape and the land system map is difficult, since the criteria followed during photo-interpretation differ very much from the assumes of our procedure. Nevertheless it can be affirmed that both the approaches are valid in increasing the information about an area.

The third is an overall qualitative evaluation of the procedure. In a relatively short time a soil-landscape map of a 23,500 ha area have been produced in a 1:50,000 scale. In some parts of the area, where the lithology is more homogeneous, the reliability of the map is very high and the discriminating capability of different soil is good. A lower reliability of the map has been detected in more lithologically complex zones of the area, that can be explained by the low information level of existing geological map due to the small scale of the document and the lacking of exact lithological data.

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References

ABDEL-HADY A.M., ROGNON P., ESCADAFAL R., POUGET M. (1991). "Contribution of Landsat data (MSS) to soil survey: application to the soil of south-western Sinai (Egypt)". *Int. J. Remote Sensing*, 12 (5):1053-1061.

AGBU P.A., FEHRENBACHER D.J., JANSEN I.J. (1990). "Soil Property Relationships with SPOT Satellite Digital Data in East Central Illinois", *Soil Sci. Soc. Am. J.* 54:807-812.

AGBU A., NIZEYIMANA E. (1991). "Comparison between Spectral Mapping Units Derived from SPOT Image Texture and Field Soil Map Units". *Photogrammetric Engineering & Remote Sensing* 57 (4):397-405

LESSANDRO V, BAGNOLI M. (1990). "Tecniche di classificazione della copertura del suolo della bassa e media valle del fiume Cedrino (Sardegna Orientale)". In *Proceeding of IV Convegno Nazionale dell'A.I.T.*, Pisa, 27-30 November 1990.

BAUMGARDNER M.F., SILVA L.F., BIHEL L.L., STONER E.R. (1985). "Reflectance Properties of Soils". *Advances in Agronomy* 38:1-44.

BHATTI A.U., MULLA D.J., FRAZIER B.E. (1991). "Estimation of Soil Properties and Wheat Yields on Complex Eroded Hills Using Geostatistics and Thematic Mapper Images", *Remote Sens. Environ.* 37:181-191.

BUSONI E., SALVADOR SANCHIS M.P., CALZOLARI C., ROMAGNOLI A., in press. Carta delle Unità di Terre dell'Alta Val d'Orcia (SI) in scala 1:35 000, C.N.R., P.F. RAISA, Firenze.

BUTTNER G., CSILLAG F. (1990). "Comparative Study of Crop and Soil Mapping Using Multitemporal and Multispectral SPOT and Landsat Thematic Mapper Data". *Remote Sens. Environ.* 29:241-249.

CALZOLARI C., MAGALDI D., SARTORI G. (1989). "I suoli argillosi a nord di Campiglia d'Orcia", *CNR Quaderni di Scienza del Suolo*, 2:65-86.

CALZOLARI C., RISTORI J., BUSONI E., CHIARUCCI A., in press. "Morphology development in a 'biancana' badland area and relationships with soils and vegetation". Presented at "Soil erosion in semiarid mediterranean areas", Taormina, Italy, Oct. 28-30, 1993.

CALZOLARI C., RISTORI J., SPARVOLI E. (1993). "Soils of *biancana* badlands: distribution, characteristics and genesis in Beccanell farm (Tuscany, Italy)", *CNR Quaderni di Scienza del Suolo*, 5: 119-142.

CALZOLARI C., SARFATTI P. (1994). "Uso dei dati LANDSAT TM per lo studio dei suoli coltivati con cereali autunno-vernini in Val d'Orcia (SI)". *Rivista Italiana di Telerilevamento*, 3: 31-36.

CASTELVECCHI A., VITTORINI S. (1967). "Osservazioni preliminari per uno studio dell'erosione in Val d'Orcia", Società Geografica Italiana, Roma: 1-18.

CHIARUCCI A., DE DOMINICIS V., RISTORI J., CALZOLARI C., in press - "Biancana badland vegetation in relation to morphology and soil in Orcia valley, central Italy", *Phytocoenologia*, Berlin-Stuttgart.

CIPRA J.E., FRANZMEIER D.P., BAUER M.E., BOYD R.K. (1980). "Comparison of Multispectral Measurements from Some Nonvegetated Soils Using Landsat Digital Data and a Spectroradiometer", *Soil Sci. Soc. Am. J.* 44:80-84.

COLICA A. (1993). *Processi erosivi in calanchi e biancane e loro implicazioni per le opere di conservazione nell'alta Val d'Orcia (Siena),* Tesi di dottorato, Università degli studi di Firenze, 163 pp.

DAVIS V.A., PEET F.G. (1976). "A method of smoothing digital thematic maps", *Remote Sensing of Environment*, Vol. 6, pp. 45-49.

DUBUQ M., DARTEYRE J.P., REVEL J.C. (1991). "Identification and cartography of soil surface erosion and crusting in the Lauragais (France) using SPOT data and a DEM", *ITC Journal* 1991-2:71-77.

ESCADAFAL R., GIRARD M.C., COURALT D. (1989). "Munsell Soil Color and Soil Reflectance in the Visible Spectral Bands of Landsat MSS and TM Data", *Remote Sens.- Environ.* 27:37-46.

FRAZIER B.E., CHENG Y. (1989). "Remote Sensing of Soils in the Eastern Palouse Region with Landsat Thematic Mapper", *Remote Sens. Environ.* 28:317-325.

GIORDANO A. (1991). "Studio della risorsa suolo e della sua conservazione mediante il telerilevamento", *Relazioni e monografie agrarie subtropicali e tropicali,* n. 109 - Istituto Agronomico per l'Oltremare, Firenze.

GURNEY C.M., TOWNSHEND J.R.G. (1983). "The use of contextual information in the classification of remotely sensed data", *Photogrammetric Engineering and Remote Sensing*, Vol. 49, No. 2, pp. 55-64.

HINSE M., BONN F., BADRAOUI M., MERZOUK A. (1990). "Application des données Landsat TM pour l'étude des caractéristiques pédologiques d'une région semi-aride du Maroc", *Photo-interprétation*, 1990-2, fascicule 1.

HORVATH E.H., FOSNIGHT E.A., KLINGEBIEL A.A., MOORE D.G., STONE J.E. (1987). "Using a Spatial and Tabular Database to Generate Statistics from Terrain and Spectral Data for Soil Surveys. Soil Survey Techniques", *Soil Science Society of America Journal,* Special Publication n.20:91-98.

IACOBACCI A., MARTELLI G., NAPPI G. (1967). "Note illustrative della Carta Geologica d'Italia", Foglio 129, S. Fiora. -Servizio Geologico d'Italia, Roma, 61 pp.

KORNBLAU M.L., CIPRA J.E. (1983). "Investigation of Digital Landsat Data for Mapping Soils under Range Vegetation", *Remote Sens. Environ.* 13:103-112.

LEWIS D.T., SEEVERS P.M., DREW J.V. (1975). "Use of Satellite Imagery to Delineate Soil Associations in the Sandy Hills Region of Nebraska", *Soil Sci. Soc. Am. Proc.* 39:330-335.

LEE K., LEE G.B. (1988). "Determination of Soil Characteristics from Thematic Mapper Data of a Cropped Organic-Inorganic Soil Landscape", *Soil Sci. Soc. Am. J.* 52:1100-1104.

LEE K., LEE G.B., TYLER E.J. (1988). "Thematic Mapper and Digital Elevation Modelling of Soil Characteristics in Hilly Terrain". *Soil Sci. Soc. Am. J.* 52:1104-1107.

LULLI L., DELOGU F., GREGORI E., MICLAUS N. (1980). "Cartografia di base per la programmazione degli interventi in aree marginali (area rappresentativa dell'alta Val d'Era - Botro dell'alpino e Renaglio)", *Annali Ist. Sper. Studio e Difesa del suolo*, vol. XI, Firenze, 33-96.

MAFFINI, G. (1987). "Raster versus vector data encoding and handling: a commentary", *Photogrammetric Engineering and Remote Sensing*, Vol. 53, No. 10, pp. 1397-1398.

MULDERS M.A. (1987). *Remote Sensing in Soil Science*, Elsevier Science Publishers, Amsterdam.

PRICE J.C. (1990). "On the Information Content of Soil Reflectance Spectra", *Remote Sens. Environ.* 33:113-121.

ROUDABUSH R.D., HERRIMAN R.C., BARMORE R.L., SHELLENTRAGER G.W. (1985). "Use of Landsat multispectral scanning for soil surveys on Arizona rangeland", *Journal of Soil and Water Conservation*, 1984 March-April: 242-245.

SANESI G. (1977). Guida alla descrizione del suolo. C.N.R., Firenze, 157 pp.

SORIANO M.D., COLICA A., TORRI D. (1992). "La influencia de la estructura y propriedades de los materiales en la evolucion de badlands", In *Estudios de geomorfologia en España. Actas de la II reunion national de badlands*, Murcia, 183-191.

SAMSON S.A., LEWIS D.T. (1991). "Numerical taxonomy of soils using spectral information of overlying range vegetation", *Geoderma* 50:1-11.

SISS, Società Italiana Scienza Del Suolo (1985). *Metodi normalizzati di analisi del suolo*, Edagricole, Bologna, 100 p.

SNEDECOR G.W., COCHRAN W.G. (1980). *Statistical methods*, Iowa State University Press, Ames, 507 p.

SU H., KANEMASU E.T., RANSOM M.D., YANG S. (1990). "Separability of Soils in a Tallgrass Prairie Using SPOT and DEM Data", *Remote Sens. Environ.* 33:157-163.

STORY, M. AND CONGALTON, R.G., 1986. "Accuracy assessment: a user's perspective", *Photogrammetric Engineering and Remote Sensing*, Vol. 52, No. 3, pp. 397-399.

THOMPSON D.L., PITTS D.E., HENDERSON K.E. (1983). "Simulation of Landsat Multispectral Scanner Response of Soils using Laboratory Reflectance Measurements", *Soil Sci. Soc. Am. J.* 47:542-546.

THOMPSON D.R., HENDERSON K.E., HOUSTON A.G., PITTS D.E. (1984). "Variation in Alluvial Derived Soils as Measured by Landsat Thematic Mapper", *Soil Sci. Soc. Am. J.* 48:137-142.

TORRI D., COLICA A., ROCKWELL D. (1994). *Preliminary study of the erosion mechanism in a* Biancana *badland (Tuscany - Italy)* - Catena, Elsevier.

TOWNSEND, F.E. (1986). "The enhancement of computer classification by logical smoothing", *Photogrammetric Engineering and Remote Sensing*, Vol. 52, No. 2, pp. 213-221.

TROTTER C.M. (1991). "Remotely-sensed data as an information source for geographical information systems in natural resource management", *International Journal of Geographical Information Systems*, Vol. 5, No. 2, pp. 225-239.

WESTIN F.C., FRAZEE C.J. (1976). "Landsat Data, its Use in a Soil Survey Program", *Soil Sci. Soc. Am. J.* 40:81-89.

WRIGHT J.J., BIRNIE R.V. (1986). "Detection of surface soil variation using high resolution satellite data: results from the U.K. SPOT-simulation investigation-", *Int. J. Remote Sensing* 7(6):757-766.