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ERMANNO BUSONI (*) & ANTONELLA COLICA (**)

INFLUENCE OF LAND USE CHANGES ON LANDSCAPE FACTORS AND CHARACTERISTICS OF A PLIOCENE BASIN

ABSTRACT: BUSONI E. & COLICA A., *Influence of land use changes on landscape factors and characteristics of a Pliocene basin*. (IT ISSN 1724-4757, 2006).

The impact of human activities on the landscape and its factors: soil, water, vegetation, geomorphology, etc., reaches nowadays unprecedented levels. A quali-/quantitative knowledge of landscape changes is needed to understand the anthropogenic influence and to create models in order to generate scenarios to assess the future trends of the landscape system. This is much more necessary when dealing with landscapes that at present are to withstand an accelerated and stronger anthropic stress. The paper's aims are to present the effects of land use changes in the 1976-1994 period on landscape factors and characteristics in the northern part of the Asso River basin (Siena, Italy). The Asso River basin is included in the «Siena Graben» located in Central Italy (Tuscany). Data on lithology, hydrological basin orders, slopes, that is slope types and their length, height as relief energy and slope gradient, landforms as type, frequency and position along the slopes and land use were acquired by aerial photograph interpretation and controlled on the ground, at the slope level. In order to analyse relationships among the data, statistical basic and cluster analyses were carried out. Results show that in the above said period land use changes covered about 15% of the studied area and influenced the persistence of about 25% landforms. Arable lands and pastures and natural grasslands show increases of about 8% and 2% respectively. Vineyards and olive groves decrease of about 2% and complex cultivation patterns of about 3%. Forested areas show a slight increase of their extensions. Taking each landform into account, it results that most of the types decrease their presence in the range from 50% to 26%; the highest value is reached by shallow seated gravitational deformation; the lowest one is marked by *biancana*. An exception is shown by *calanco* potential areas with an increase of about 5%. *Balza* remain constant in time. The effects of land use changes on the landscape are explained both qualitatively and quantitatively. Cluster analysis shows that in general land use changes are mainly linked to slope gradient, to previous land use, to slope type and to lithology. Landforms are linked to all of the said factors. Slope length and height appear to be linked but statistically very distant from the other landscape factors. Statistical and cluster analyses confirm most of what highlighted by the aerial photograph interpretation and ground controls. The adopted methodology can be used in handling data for landscape analysis and in Geographical Information System applications and modelling, as statistical parameters and derivates show strong weights and linkages among the variables taken into account.

KEY WORDS: Land use changes, Landform, Anthropogenic influence, Neogenic basin, Italy.

(*) *CNR - IRPI Unità Staccata di Firenze.*
(**) *Geologist consultant.*

RIASSUNTO: BUSONI E. & COLICA A., *Influenza delle variazioni di uso del suolo sui fattori e caratteristiche del paesaggio di un bacino pliocenico.* (IT ISSN 1724-4757, 2006).

L'impatto delle attività umane sul paesaggio ed i suoi fattori quali suolo, acqua, vegetazione, geomorfologia etc., raggiunge attualmente livelli senza precedenti. La conoscenza quali-/quantitativa delle variazioni del paesaggio è necessaria per capire l'influenza antropogenica e creare modelli di scenari miranti alla valutazione delle future tendenze del sistema paesaggio. Ciò è tanto più è necessario quanto più i paesaggi devono contrastare una accelerata e più forte azione antropica. Questo articolo presenta gli effetti dei cambiamenti di uso del suolo, inerenti all'intervallo temporale 1976-1994, sui fattori e caratteristiche del paesaggio nell'area settentrionale del bacino del fiume Asso (Siena, Toscana). Il bacino del fiume Asso fa parte della fossa tettonica nota come «Graben di Siena». I dati su litologia, su ordine di bacino, su versante quali tipo di versante e propria lunghezza, altezza, intesa come energia di rilievo e pendenza, sulle forme intese come tipo, frequenza e loro posizione sul versante e su uso del suolo sono stati acquisiti mediante la fotointerpretazione e controllati sul terreno, a livello di versante. Per analizzare le relazioni tra i dati, questi sono stati trattati con analisi statistica e multivariata (cluster). I risultati mostrano che nel periodo di riferimento le variazioni di uso del suolo coprono circa il 15% dell'area studiata ed influenzano la persistenza di circa il 25% delle forme. Il seminativo e il prato-pascolo mostrano un aumento rispettivamente di circa 8% e 2%. Vigneti e oliveti decrescono di circa il 2% e le coltivazioni miste di circa il 3%. Le foreste mostrano un leggero incremento della loro estensione. Delle singole forme prese in esame risulta un decremento delle presenze variabile dal 50% al 26%; il maggior valore è espresso dalle deformazioni gravitative poco profonde; il minore è segnato dalle biancane. Un'eccezione a questa tendenza è mostrata dalle aree potenziali a calanco che mostrano un incremento di circa il 5%. Le balze rimangono costanti nel tempo. L'influenza delle variazioni di uso del suolo sul paesaggio è spiegata sia qualitativamente che quantitativamente. Le analisi cluster mostrano che, in generale, le variazioni di uso del suolo sono principalmente legate alla pendenza del versante, al precedente uso del suolo, al tipo di versante ed alla litologia. Le forme sono legate a tutti i suddetti fattori. La lunghezza e l'altezza del versante appaiono essere legate tra loro, ma statisticamente molto distanti dagli altri fattori del paesaggio. Le analisi statistiche e multivariate cluster confermano la maggior parte di quanto evidenziato dalla fotointerpretazione e dai controlli sul terreno. La metodologia adottata può essere usata per la gestione dati per l'analisi del paesaggio, per l'applicazione e l'uso di modelli GIS, dato che i parametri statistici e le loro derivate mostrano forti pesi e connessioni tra le variabili prese in esame.

TERMINI CHIAVE: Variazione di uso del suolo, Morfologia, Influenza antropica, Bacino neogenico, Italia.

INTRODUCTION

The impact of human activities on the landscape and on its factors reaches nowadays unprecedented levels. The modifications of the landscape and their magnitudes have both spatial and temporal components and these components are integral to an understanding of landscape sensitivity (Thomas, 2001). Such modifications also determine in part the vulnerability of territories to economic or socio-economic and/or political perturbations. Land use changes can cause severe impacts on the landscape. Changes in land cover, biophysical attributes of the Earth's surface as related to land use, human purposes or intents applied to these attributes, are among the most important parameters to be considered and analysed in order to check the state of landscape systems (International Geosphere - Biosphere Programme, 2004).

Many studies have related land use changes to population growth and have tried to take climatic, anthropogenic and natural influences into account for preserving the balance of ecosystems. For instance, O'Donnell (2004) studied the land use changes in Southwestern United States in the period 1945-1992 and, by analysing data for four major crops and their evapo-transpiration rates, tried to determine what changes led to an increase of yields and to preserve the resources of the landscape system.

If studies on land use changes do exist at a local scale, such as that by Weller (2004), on Rhode River Watershed (USA), or that by Muller (2003), on Central Highlands (Vietnam), detailed studies on landforms variations as a consequence of land use changes at the watershed scale are rare. Busoni & Colica (2003) analysed the relationships between linears, landforms and geology in the Northern Asso River basin, with some respects to anthropic effects during the period 1976-1994.

A quali-quantitative or detailed knowledge of changes in the landscape system is therefore still to be fully acquired, the anthropogenic influence has to be understood and the creation of models to generate scenarios to estimate the sensitivity and the future trends of the evolution of the landscape systems is needed.

This paper aims to present land use changes in the period 1976-1994 and their influence on landscape factors and characteristics in the northern area of the Asso River basin (Siena Province, Italy). The study was carried out by adopting the landscape ecological analysis conceptual approach and methodologies (Rohdenburg, 1989; Naveh & Lieberman, 1994).

MATERIALS AND METHODS

The study area, 173 km^2, is located in the northern part of the Asso River drainage basin (fig. 1). It is included in the northern part of the Siena Graben (Costantini & *alii*, 1982), a NW-SE tectonic depression.

The landscape is hilly with variable slope gradient from 5 to over 47%; it includes small mountain areas which are part of the Middle Tuscany Ridge, in the NNE and E sectors, and where the Tuscan Series (Trevisan & Giglia, 1978) outcrops. There are also level areas consisting of stream terraces or alluvial deposits of the Asso River and of its tributaries.

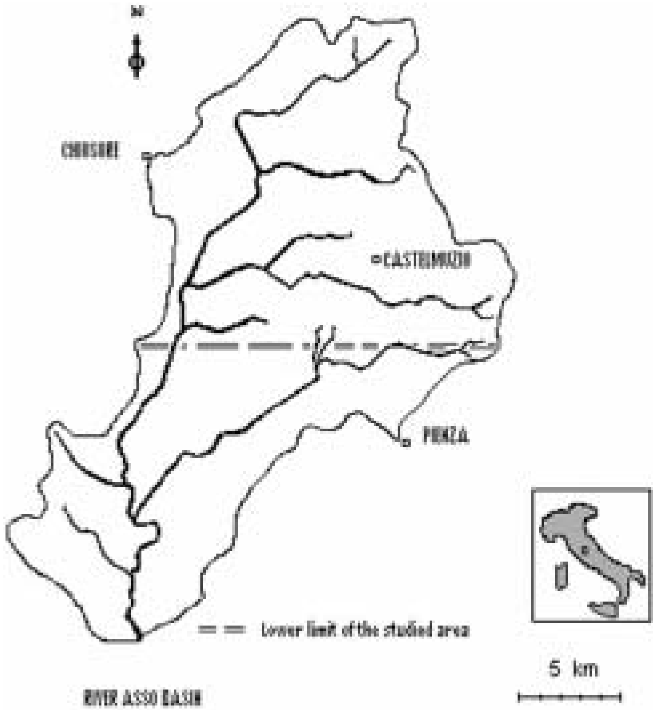

FIG. 1 - Study area in the northern part of the Asso River drainage basin. The line is the lower limit of the study area.

In landscape analysis, landscape factors and characteristics are usually chosen hierarchically in such a way to achieve the analysis aims. In the present study, the analysed landscape factors were:

- lithology;
- hydrological basin order (from now on, only the words basin and basin order are used);
- slope type and its characteristics: length (m), height (as relief energy, m), aspect (subdivision in sectors of 22.5° each), slope gradient. As in a basin there can be more than two slopes, the slope type was attributed on the basis of the more extended found one. The characteristics of each slope type were individually measured. According to Schoeneberger (2002), the slope type was described and designed along two directions: up-and-down slope (perpendicular to the contour) by a first letter; and across slope (along the horizontal contour) by a second letter by using two following symbols: **l** for linear, **v** for convex, **c** for concave (fig. 2).
- landform type and its position in the slopes; the position was considered as a characteristic;
- land use in 1976;
- land use in 1994;
- land use difference between 1976 and 1994.

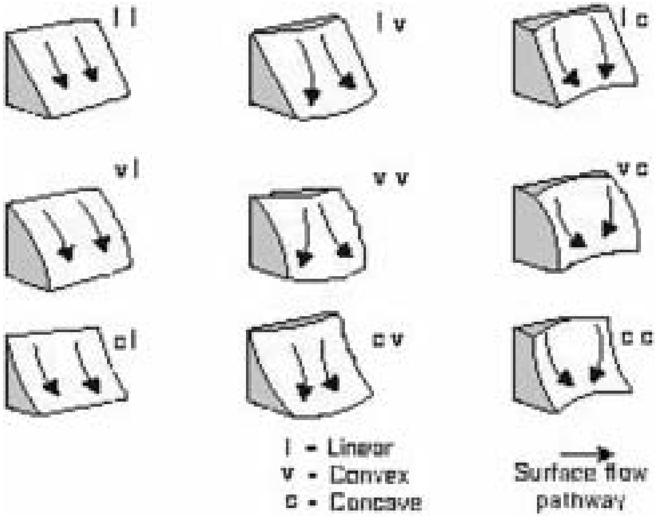

FIG. 2 - Slopes types according to Shoeneberger (2002). **l**: linear; **v**: convex; **c**: concave. The first letter perpendicular to the contour, the second letter across slope. Figure modified from Shoeneberger (2002).

All the factors and characteristics were coded. Basins, slopes, landforms and land use were distinguished and analysed on the basis of lithology.

Analysis of the morphology of slopes, of landforms and of land use was carried out by aerial photograph interpretation on 1976 and 1994 aerial surveys (1:13000 scale) of the Regione Toscana and by ground controls.

Pliocene stratigraphy has been here synthesized from Losacco (1963), Jacobacci & *alii* (1969), Boccaletti & *alii* (1987) and Berti & *alii* (1992):

pa - marine clays and sandy clays with conglomerate lenses (Early - Middle Pliocene); they form the largest outcrop;

ps - sand and clayey sands with lenses or layers of conglomerate or lignite, or silty clay or clay (Middle Pliocene);

pc - polygenetic conglomerates, with varying relationships with other Pliocene deposits.

In the study the following landforms were taken into account:

- *calanco* according to: Cori & Vittorini (1965); Vittorini (1971, 1977, 1991); Guerricchio & Melidoro (1979a, 1979b); Rodolfi & Frascati (1979); Mazzanti & Rodolfi (1988); Torri & Monaci (1991); Bazzoffi & *alii* (1997); Chiaverini & *alii* (1999); Colica (1992, 2000); Moretti & Rodolfi (2000); Busoni & *alii* (1998); Busoni & Colica (2002, 2003). It is a small drainage basin, formed by small talwegs separated by narrow, more or less sharp ridges with slope angles depending on the physical and mechanical characteristics of the sediments. The landform mainly develops on steep slopes (> 25%), on clayey sediments, that in times may be also stratified with textures coarser than clay. The *calanco* is generally more than 20 m deep. In this study also gullies (Bergsma & *alii*, 1996) readable by aerial photograph interpretation were considered as *calanco*.
- «*calanco* potential area» according to Busoni & Colica (2002, 2003): it is a complex hill slope, generally steeper than 25%. It may represent either a transitional stage from a grazed or a cultivated area to a *calanco*; or a transition from a *calanco* area to a permanent, vegetated one. In the first case, features of erosional incipient *calanco* forming processes are evident; in the second case the *calanco* features are still recognisable (such as the old headcut and erosional and depositional forms), notwithstanding the presence of vegetation;
- shallow seated gravitational deformation according to Colica & Guasparri (1990), Busoni & Colica (2002, 2003): they develop on hills with slope gradient less than 20% and they may acquire elliptical, convex form. This landform develops on clay or clay with sandy lenses or layers, or on sandy clay lenses present in ps. The main axis of shallow-seated gravitational deformation may be shorter than 60 m but longer than that of *biancane*. Generally it occurs in clusters;
- levelled shallow-seated gravitational deformation (Busoni & Colica, 2002, 2003): the landform has been levelled but its elliptical base section is still visible;
- *biancana* is a dome-shaped landform, mostly present in clusters on hill slopes, usually never steeper than 25%. *Biancana* is generally lower than 20 m, with a sub-horizontal pediment (Guasparri, 1978; Colica & Guasparri, 1990; Guasparri, 1993, Busoni & Colica, 2003). This landform mainly develops on **pa** but can also be found on clay lenses in **ps**. The dome has asymmetrical slopes, with the southern face steeper than the northern one. The landform can be bare, half vegetated (mainly on the northern slope) or fully vegetated;
- levelled *biancana* according with Busoni & Colica (2001, 2002, 2003); the landform has been levelled but its elliptical, or circular base section is still visible;
- earthflow is a landform characterised by downslope translation of soil and weathered rock over a discrete basal shear surface within well-defined lateral boundaries (Soil Survey Staff, NRCS, 2001). This convex landform usually has dimensions larger than those of the shallow-seated gravitational deformation. It develops in clay sediments, with or without sand interlayers. The accumulation may be present at the foot of the scarp or along the slope, or at the foot of the slope;
- rock fall develops in **ps**, **pc**, ST and in sand lenses present in **pa**. It is characterised by a vertical or sub-vertical scarp;
- *balza* is a nearly vertical cliff, several meters high, mainly developed in **ps** and **pc**.

The position of the landform in the slope was described along a transect that runs up-and-down the slope (Schoeneberger, 2002). The position is indicated by the symbols: «a» if the landform is located on summit and shoulder of the slope; «m» if the landform is located on backslope, «b» if the landform is located on footslope and toeslope (Schoeneberger, 2002); and by «all» when the slope is completely covered by the landform (fig. 3).

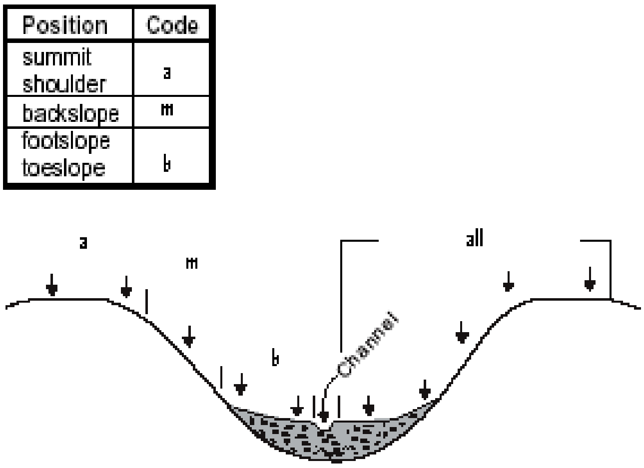

FIG. 3 - Landform positions on the slopes. Figure modified from Shoeneberger (2002).

A landform located in more positions along the slope is represented by as many letters as many positions it occupies (e.g.: for a landform located on the shoulder and on the footslope, the symbol «ab» is used).

Land use in 1976 and 1994 years was analysed according to «Codice CORINE» (Regione Toscana, 2000). In this study CORINE class names were used, but instead of the numerical original codes, the following ones are adopted: «f» for arable soils, «b» for forested area, «af» for olive groves and vineyards, «p» for pastures and natural grassland, «n» for bare soil area, «mixed» for complex cultivation patterns. These classes were represented by their relative cover percentage on the slopes.

In order to evaluate the relationships, the linkages and the relative effects among the different landscape factors and their characteristics, basic, circular and multivariate statistical analyses (cluster analysis) were carried out according to Seal (1964), Sneath & Sokal (1973), Davis (1986), Webster & Oliver (1990), Wildi & Orloci (1990), Fisher (1993) and Podani (1994). Multivariate statistical analysis is a sound method adopted in data mining for ecological and landscape analysis (Busoni & *alii*, 1995). To perform the multivariate statistical analysis, scores were assigned to variables, that is, in this study, to landscape factors and characteristics according to tab. 1, with the exception of slope length, height and gradient whose original data were ranked. The adopted rank was: every 5 m for slope length and height, and every 0.05 for slope gradient. The median values of the ranks were attributed to the original slope gradient data. Scores were given using an arbitrary ranking, as ranked variables had to be used all through the multivariate analysis (Busoni & *alii*, 1995), using a nominal scale. Scores are usually used to distinguish each factor or characteristics from all the other ones. The score should be considered as a numerical label given to a non-parametric variable. There is no need to link the used score scale to a particular environmental or geological significance. Every basic and multivariate statistical analysis was carried out only on pair wise cases, this means that the missing data were deleted.

The data were linearly standardized according to the percentage of their presence all over the study area. Circu-

TABLE 1 - Scores assigned to landscape factors and characteristics. Slope types: see fig. 2, according to Shoeneberger (2002). Landforms: C: *calanco*, CPA: «*calanco* potential area», SSGD: shallow seated gravitational deformation, B: *biancana*, Fcr: rock fall, Fco: earthflow, Bz: *balza*, Bl: levelled *biancana*, SSGDl: levelled shallow seated gravitational deformation. Landform positions: see fig. 3. (*) The score is the sum of the products of the percentage for the scores of the present land uses

Slope type	score
«vv»	**1.00**
«lv»	**1.25**
«cv»	**1.50**
«vl»	**1.75**
«ll»	**2.00**
«cl»	**2.25**
«vc»	**2.50**
«lc»	**2.75**
«cc»	**3.00**
Landform	**score**
C	**3.50**
CPA	**1.60**
SSGD	**1.35**
B	**1.40**
Fcr	**3.00**
Fco	**1.25**
Bz	**5.00**
Bl	**1.00**
SSGDl	**1.00**

	Lithology	score
clay	**pa**	**3.00**
clay and sand	**pa**	**3.00**
sand	**ps**	**2.00**
sand and clay	**ps**	**2.00**
conglomerate	**pc**	**1.50**
sand and conglomerate	**ps**	**2.00**
Tuscan Series	ST	**1.00**
	Landform position	**score**
	«a»	**3.00**
	«m»	**2.00**
	«b»	**1.50**
	«all»	**5.00**
	Land use	**score**
arable soils	«f»	**1.20**
forested area	«b»	**1.45**
olive groves and vineyards	«af»	**1.25**
pastures and natural grassland	«p»	**1.50**
bare soil area	«n»	**0.01**
complex cultivation patterns	«mixed»	**(*)**

lar data of slope aspects were used and their statistical *momenta* treated.

RESULTS AND DISCUSSION

The distribution of the basins, their total extension and mean areas, on the different lithologies are shown in tab. 2. The basins on **pa** are the most numerous and show the smallest mean area, while those on ST are the most extended.

Most of the basins (tab. 3) are characterised by «**ll**» slope type followed by the «**cc**» one. The «**ll**» slope type is to be considered as the slope type that underwent the heaviest anthropic activity. The fact is well expressed on slopes on **pa** and is easily readable by aerial photograph interpretation and confirmed by controls on the field. Most of «**ll**» slope types pertain to first order basins, the smallest and easiest to be levelled for agricultural uses.

TABLE 2 - Basins on different substrata, number, percentage, total extension and mean area. **pa**: pliocenic clays; **ps**: pliocenic sand; **pc**: pliocenic conglomerates; ST: Tuscan series

Lithology	Number of basins	% of the basins	Total area (km^2)	Mean area (ha)
pa	2779	65.3	72.2	2.60
ps	1303	30.6	72.63	5.57
pc	74	1.7	6.6	8.92
ST	98	2.3	16.24	16.57

TABLE 3 - Slope types as relative percentages. Basins according to their order as a function of slope types

Slope type	Slope type %	ord1	ord2	ord3	ord4	ord5
«cc»	42.42	1112	539	121	25	1
«ll»	50.58	1931	191	20	2	0
«lc»	4.34	130	39	13	1	1
«lv»	0.68	25	4	0	0	0
«cl»	0.71	24	4	2	0	0
«vl»	0.75	29	3	0	0	0
«cv»	0.31	9	4	0	0	0
«vv»	0.21	8	1	0	0	0

Regardless the basin order and lithologies on which the slopes develop, in tab. 4 the «**ll**» slope type shows the lowest values for mean slope length, height and gradient. This suggests the effects of anthropic activity reshaping the slopes by agricultural uses and repeated levellings.

Tab. 5 shows the statistics of the characteristics of slopes as functions of only the numerically significant lithological substrata, slope types and basin orders. The values of the mean length of the «**ll**» slope type are generally lower than those of the «**cc**» and «**lc**» slope types; this applies to the slopes of the 1st and 2nd order basins on **pa**, and to those of the 1st, 2nd and 3rd order basins on **ps.** The bifurcation ratios, applied to the basins of the first, the second and third order, give the highest values in presence of «**ll**» slope type on **pa** and on **ps**. The shown bifurcation ratios are larger than the homologous ratios of the basins characterised by «**cc**» and «**lc**» slope types.

The great number of 1st order basins on **pa** characterized by «**ll**» slope type is a consequence of levelling and reshaping of different slope types to the «**ll**» slope type.

To understand whether the human activities had affected the slope aspects or not, circular analysis on data of slope aspects was used and statistical *momenta* treated. In tab. 6 circular statistics on data covering the population of different slope types are shown. The Rayleigh test of uniformity shows that no preferential slope aspect is evidenced, except for «**cl**» and «**vl**» slope types. This means that the anthropic action did not choose preferential slope aspects by levelling and reshaping, perhaps because no very remunerative crop had to be cultivated.

Landforms positions are ubiquitous on the slopes with the exception of the backslope position which is the least represented. When the backslope position is represented, it occurs generally on the less frequent slope types, i.e. on «**lv**», «**cl**», «**vl**», «**cv**» and «**vv**» (see tab. 4). This means that where the anthropic action is exerted, the backslope is preferred.

Landforms on **ps**, **pc** and ST are not analysed here, as only *balza*, *calanchi* and rock falls characterize the slopes developed on these lithologies. Usually these landforms occur along almost the entire slopes on which the anthropic action is rarely exerted. Their frequencies result not statistically significant.

TABLE 4 - Average characteristics of all the slope types and their distribution on the different substrata

Slope type	Slope length (m)	Slope height (m)	Slope gradient	N. of basins on pa characterized by the slope type in column 1	N. of basins on ps characterized by the slope type in column 1	N. of basins on pc characterized by the slope type in column 1	N. of basins on ST characterized by the slope type in column 1
«cc»	323	42	0,18	865	842	45	46
«ll»	109	9	0,09	1665	411	19	45
«lc»	180	27	0,18	135	35	8	6
«lv»	222	33	0,21	25	4	0	0
«cl»	203	31	0,18	29	1	0	0
«vl»	193	39	0,24	25	6	0	1
«cv»	130	27	0,23	13	0	0	0
«vv»	176	29	0,18	9	0	0	0

TABLE 5 - Bifurcation ratios and statistics of the characteristics of slope types as a function of the substrata and of the order of the basins

Lithology	**pa**	**pa**	**pa**	**pa**	**pa**	**pa**	**pa**	**pa**	**pa**
Slope type	«cc»	«cc»	«cc»	«ll»	«ll»	«ll»	«lc»	«lc»	«lc»
Order of the basin	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Number	469	308	74	1499	142	14	97	28	10
Bifurcation ratio	1.5	4.2		10.5	10.1		3.5	2.8	
Slope mean length (m)	152.14	336.49	854.46	133.52	295.60	774.29	144.23	317.86	385.00
Mean of slope gradient	0.21	0.17	0.11	0.20	0.17	0.11	0.20	0.19	0.15
Lithology	**ps**	**ps**	**ps**	**ps**	**ps**	**ps**	**ps**	**ps**	**ps**
Slope type	«cc»	«cc»	«cc»	«ll»	«ll»	«ll»	«lc»	«lc»	«lc»
Order of the basin	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Number	576	210	44	387	25	4	20	10	3
Bifurcation ratio	2.7	4.8		15.5	6.2		2.0	3.3	
Slope mean length (m)	193.16	465.43	1056.82	151.55	290.40	475.00	190.00	365.00	1033.33
Mean of slope gradient	0.19	0.15	0.14	0.17	0.17	0.18	0.21	0.19	0.13

TABLE 6 - Circular analysis of slope aspects

	«cc» **slope type**	«ll» **slope type**	«lc» **slope type**	«lv» **slope type**	«cl» **slope type**	«vl» **slope type**
Observations	1755	2124	174	28	27	31
Aspect mean vector (μ)	19.13°	147.52°	21.78°	69.32°	123.96°	103.55°
Length of mean vector (r)	0.06	0.1	0.17	0.4	0.32	0.15
Circular variance	0.94	0.9	0.83	0.6	0.68	0.85
Circular standard deviation	134.72°	124.23°	108.48°	77.78°	85.95°	110.88°
Standard error of mean	15.33°	9.20°	18.31°	18.43°	23.36°	47.05°
Rayleigh test of uniformity (p)	0	0	0.01	0.01	0.06	0.48

The presence of landforms in definite positions on the different slope types, on **pa,** is shown in tab. 7. Only the more statistically significant slope types and landform positions on the slope are taken into account. On **pa**, most of the landforms occur along the entire slope, from the summit to the toeslope. On **«cc»** slope type, the more frequent landform types on the higher part of the slope (summit and shoulder) are *calanco*, *biancana*, shallow-seated gravitational deformations and *calanco* potential areas. Few landforms are found on the lower part of the slopes (footslope and the toeslope), usually *calanco* and *biancana*. On **«ll»** slope type, on the summit and the shoulder, mainly shallow seated gravitational deformations, *biancana*, *calanco* and some rock falls are present. *Calanco* is the most frequent landform on footslope and toeslope where some *calanco* potential areas and shallow seated gravitational deformations appear.

The effects of anthropic activity are represented by the levelled *biancana* and levelled shallow seated gravitational deformations. Mainly the **«cc»** and **«ll»** slope types are interested by levelled shallow-seated gravitational deformations. This landform can be found ubiquitously on the slope, occurring mainly on all and on the summit and shoulder of the slopes. Few cases of presence of this landform are recognised in the lower part of the slopes.

On **«ll»** and **«cc»** slope types, levelled *biancana* was never found in the lower position; on the contrary, this landform was frequent on the summit and shoulder position and along the entire slope.

TABLE 7 - Number of landforms on **pa**, according to their position on the slopes of most statistically significant slope types, in 1994

	pa «cc»			**pa «ll»**			**pa «lc»**		
Landform	position «a»	position «b»	position «all»	position «a»	position «b»	position «all»	position «a»	position «b»	position «all»
Fco	1	1	0	1	1	0	0	0	0
Fcr	1	0	0	3	0	0	0	0	0
B	5	2	39	10	0	50	3	0	5
SSGD	4	1	13	16	2	30	0	0	0
CPA	2	1	7	0	6	11	0	0	0
C	12	5	75	9	18	96	3	4	1
SSGDl	23	7	40	8	1	58	1	0	3
Bl	4	0	18	2	0	23	1	0	0

Fig. 4 shows the land uses changes occurred in the period 1976-1994, as percentages relative to the presence of each slope types, regardless the lithologies. The figure shows an increase of arable soils in every type of slope. Increases of pastures and natural grassland are present on «**cc**» and «**ll**» slope types. Forested areas increase on «**lc**» slope type.

In the considered time period, all over the analysed area, arable lands and pastures and natural grasslands show increases of about 8% and 2% respectively. Vineyards and olive groves decrease of about 2% and complex cultivation patterns of about 3%. Forests slightly increase their extensions.

In particular, tab. 8 shows the relative percentage variations of land use on the different slope types, on the two main lithologies, **pa** and **ps**. It appears that the arable soils increases in every case and the pastures and natural grasslands increases only on «**cc**» and «**ll**» slope types. As a consequence of this fact, all the remaining land uses decrease, with the exception of forested areas that shows an increase on «**lc**» slope type.

Fig. 5 and fig. 6 show, clockwise from top left, the frequency distributions referred to slope gradient intervals, on **pa** and **ps** respectively, of the slopes without landforms and without land use variations, of the slopes with the presence of landforms, with or without land use variations and, finally, of the slopes with only land use variations. On slopes on **pa,** land use variations occur whatever are the slope gradient intervals and regardless of the presence or not of the landforms. On slopes on **ps**, it is remarkable that up to the slope gradient limit of 0.325, the land use variations occur regardless the presence of landforms; over that limit, no land use variations are found in presence of landforms, which are mainly represented by well-developed *calanco*.

In the period 1976 - 1994, all over the study area, as a consequence of land use changes, only the number of the *calanco* potential area increases and the number of *balza* remains constant. All the other landforms, levelled landforms included, decrease (tab. 9). The decrease of the levelled landforms is due to the continuous reshaping of the slopes so that their base sections became indiscernible by aerial photograph interpretation and field surveys.

The relative variations of presence of the landforms as a function of the land use changes in the period from 1976 to 1994, taking into account only the numerically significant data of **pa** lithology and of «**cc**» and «**ll**» slope types were analysed. The presence of the landforms on different slope types is linked to the relative increase of land use seen in tab. 8. This fact took to the variations of presence of the landforms as shown in tab. 10. While changing the land use, several characteristics of the landscape subjected

FIG. 4 - Percentage of land use changes relative to the absolute presence of each slope type.

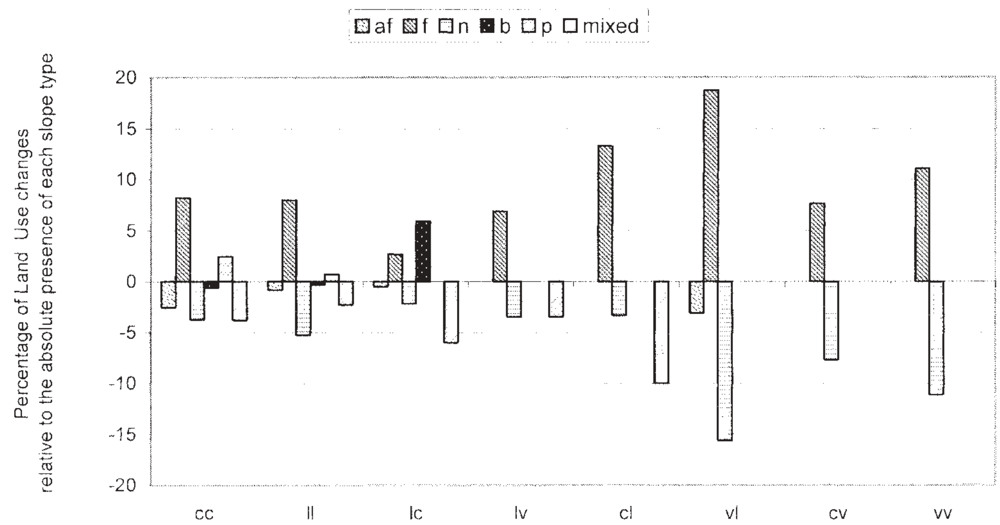

TABLE 8 - Relative percentage variations of land use in the period 1976 - 1994 on different slope types, on **pa** and **ps** lithologies

Land use	pa «cc»	pa «ll»	pa «lc»	pa «lv»	pa «cl»	pa «vl»	pa «cv»	pa «vv»	ps «cc»	ps «ll»	ps «lc»
«af»	–0.69	–0.18	–0.74	0.00	0.00	0.00	0.00	0.00	–4.29	–3.13	0.00
«f»	+12.12	+7.99	+2.94	+8.00	+10.34	+24.00	+7.69	+11.11	+4.40	+8.41	+2.94
«n»	–7.74	–6.37	–0.74	–4.00	–3.45	–20.00	–7.69	–11.11	0.00	–1.68	–8.82
«b»	–0.23	–0.24	+5.15	0.00	0.00	0.00	0.00	0.00	–0.36	–0.24	+11.76
«p»	+0.92	+0.72	0.00	0.00	0.00	0.00	0.00	0.00	+3.69	+0.72	0.00
«mixed»	–4.39	–1.92	–6.62	–4.00	–6.90	–4.00	0.00	0.00	–3.45	–4.09	–5.88

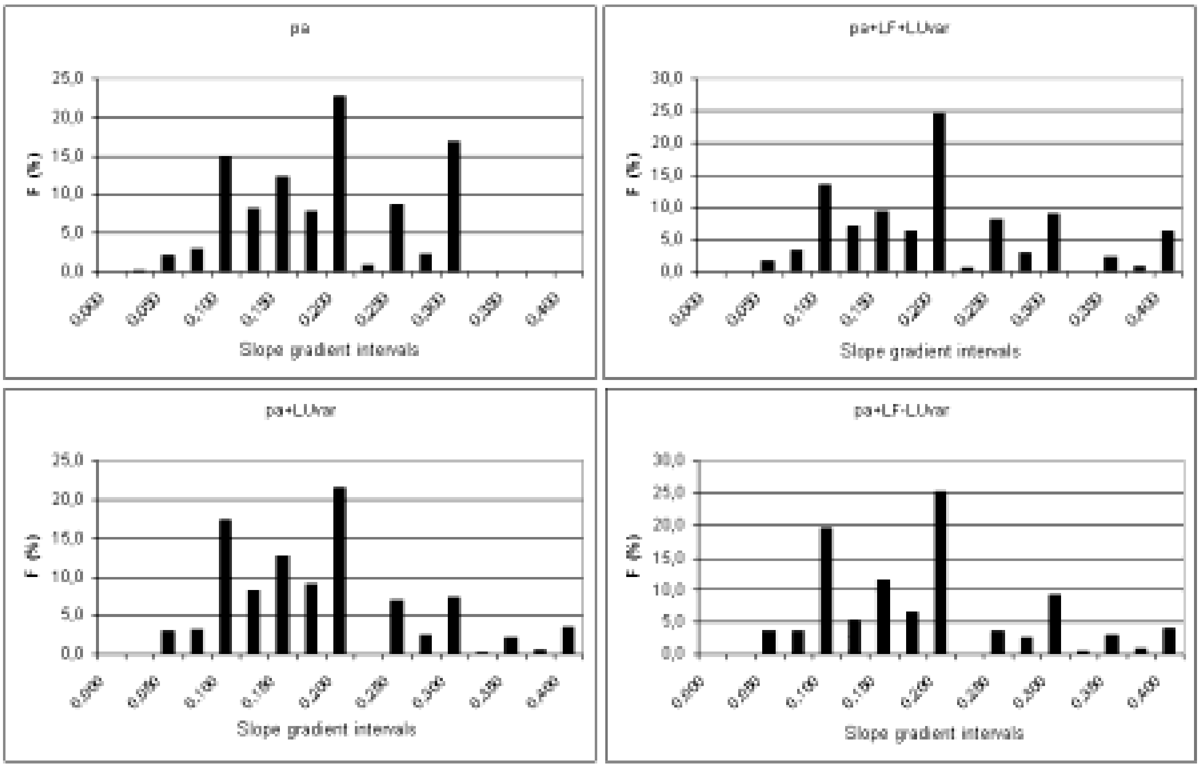

FIG. 5 - From top left, clockwise; slope gradient frequencies: on pliocenic clayey sediments (**pa**); on **pa** with landforms and with land use changes (**pa**+LF+LUvar); on **pa** with landforms and without land use changes (**pa**+LF-LUvar) and on **pa** with land use changes (**pa**+LUvar).

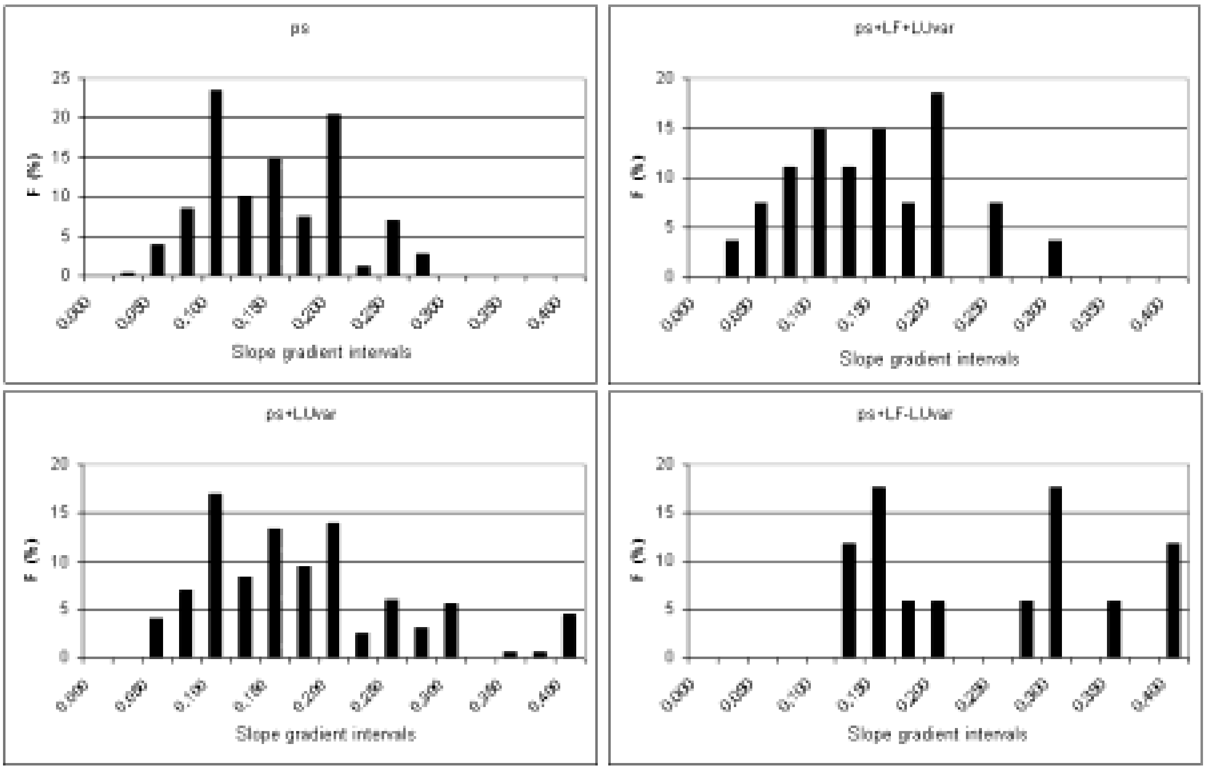

FIG. 6 - From top left, clockwise; slope gradient frequencies: on pliocenic sandy sediments (**ps**); on **ps** with landforms and with land use changes (**ps**+LF+LUvar); on **ps** with landforms and without land use changes (**ps**+LF-LUvar) and on **ps** with land use changes (**ps**+LUvar).

TABLE 9 - Variations of landforms all over the study area in the period 1976-1994

Landforms	Variations of landforms types in the period 1976 - 1994 Absolute value	%
C	–108	–34.9
CPA	3	5.5
B	–14	–25.9
Bl	–39	–68.4
SSGD	–15	–50.0
SSGDl	–85	–54.5
Fco	–8	–29.6
Fcr	–22	–25.3
Bz	0	0
Totals	–288	–36.9

TABLE 10 - Total loss, as percentage, and variations of landform presence as a consequence of land use changes on «cc» and «ll» slope types, on **pa**

On pa, on «cc» slope type							**Total loss**
Landforms	**«f»**	**«af»**	**«p»**	**«b»**	**«n»**	**«mixed»**	**%**
C	5				–4	–3	**28.57**
CPA							
B	3				–4		**25.00**
Bl		2				–6	**66.66**
SSGD	7				–10	–3	**46.15**
SSGDl	4		2		–7	–4	**45.45**
Fco					1	–1	**0.00**
On pa, on «ll» slope type							**Total loss**
Landforms	**«f»**	**«af»**	**«p»**	**«b»**	**«n»**	**«mixed»**	**%**
C	18			–5	–17	–5	**33.00**
CPA			–5			5	**0.00**
B	4		1		–9		**44.44**
Bl	3	1			–10	–4	**71.42**
SSGD	27		–15		–26	–15	**51.78**
SSGDl	12		–10		–15	–2	**55.55**
Fco							

to the new land uses are inherited from the old ones. Among the inherited characteristics, landform distribution and presence must be considered. For any land use, some landforms were subjected to human activity and an increase of the levelled ones can be expected. The increase or decrease of some other landforms, relative to different land uses, are to be summed to, or subtracted from the relative precedent ones. For example, the levelled shallow-seated gravitational deformations show an increase in the arable soils in front of a decrease in bare soil areas: this means that some of the bare soil areas were subjected to a land use change into arable soils. The total loss, as percentage, of the landforms is higher on **«ll»** than on **«cc»** slope type, the fact showing the effect of anthropic activities on the landscape.

On **ps**, changes in land use are generally from bare soil areas to forested areas or complex cultivation patterns. No distinction can be made on the slope type characterization. Only *calanco* and *balza* are recognized, which always interest the entire slope. These two landforms are rare and limited to those slopes only seldom affected by land use changes, being the land use represented mainly by complex cultivation patterns and forested areas.

MULTIVARIATE ANALYSIS

Cluster and multivariate statistical analysis can help in pointing out deeper relations among the several considered landscape factors and characteristics. Hierarchical clustering is generally represented by a dendrogram (tree diagram) depicting between-cluster relationships. Levels at which two clusters are fused are meaningful: they correspond to within-cluster homogeneities. Cluster analysis was carried out by using Euclidean distance, with complete linkage.

Cluster analysis on the 9 main landscape factors and characteristics led to the tree diagram (fig. 7). According to the linkage distances shown in the amalgamation schedule (tab. 11), four clusters can be considered: the first one formed by slope length, the second one formed by slope height, the third one including landform presence and position on the slope and slope type; the last cluster is formed by the other five members. Land use in 1976 and land use in 1994, land use difference in the time period and slope gradient are very near, not too far from lithology. Slope length and slope height are far from each other and quite

TABLE 11 - Amalgamation schedule for the clustering of variables in fig. 7

Linkage distance	Obj. n. 1	Obj. n. 2	Obj. n. 3	Obj. n. 4	Obj. n. 5	Obj. n. 6	Obj. n. 7	Obj. n. 8	Obj. n. 9
				Amalgamation Schedule Complete Linkage Euclidean distances					
16.4259	LU76	LU94							
19.7722	SLPGRAD	LUDIFF							
41.7503	SLPGRAD	LUDIFF	LU76	LU94					
91.3543	**LITHO**	**SLPGRAD**	**LUDIFF**	**LU76**	**LU94**				
300.0810	LITHO	SLPGRAD	LUDIFF	LU76	LU94	SLPTYPE			
461.7451	LITHO	SLPGRAD	LUDIFF	LU76	LU94	**SLPTYPE**	**LFORMPOS**		
793.5162	**SLPLNGTH**	SLPHGHT							
1354.143	LITHO	SLPGRAD	LUDIFF	LU76	LU94	SLPTYPE	LFORMPOS	SLPLNGTH	**SLPHGHT**

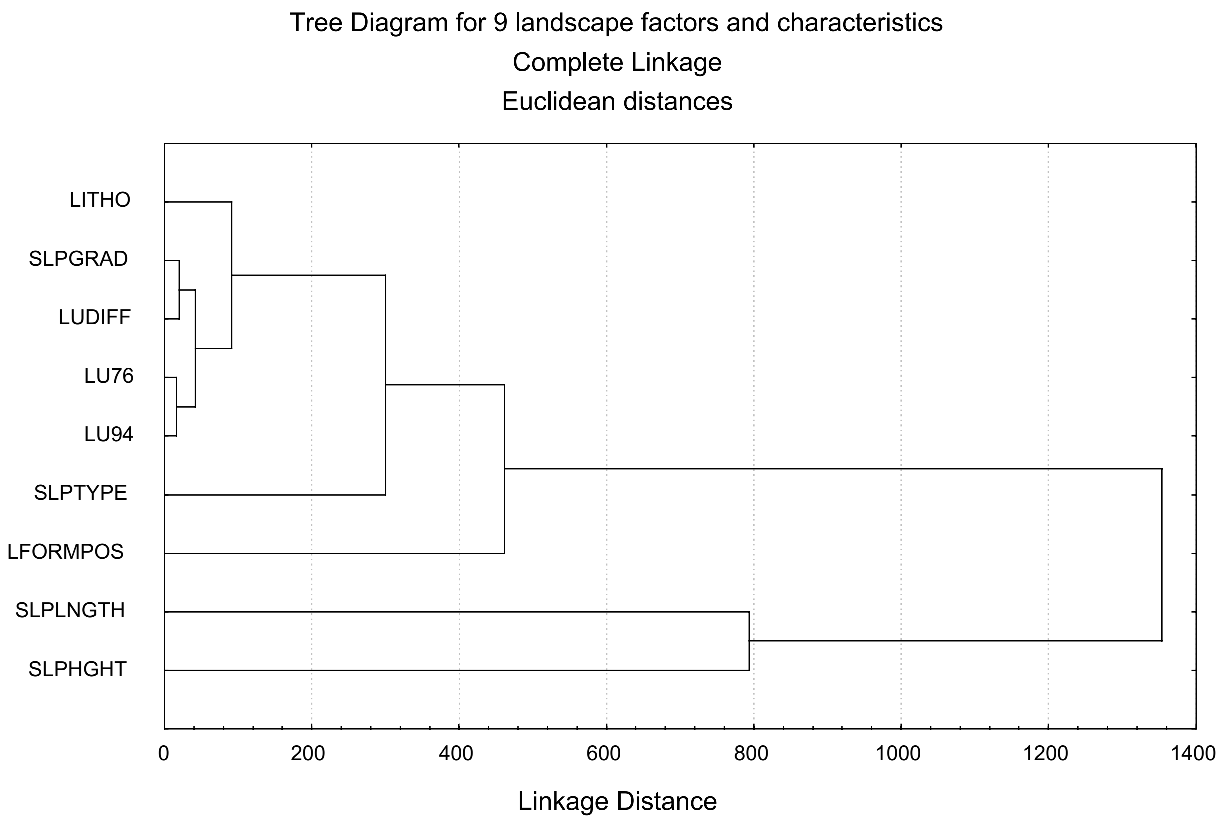

FIG. 7 - Tree diagram for landscape factors and characteristics.
LITHO: lithology; SLPGRAD: slope gradient; LUDIFF: land use difference between 1976 and 1994; LU76: land use in 1976; LU94: land use in 1994; SLPTYPE: slope type; LFORMPOS: landforms and their position in the slopes; SLPLNGTH: slope length (m); SLPHGHT: slope height (m).

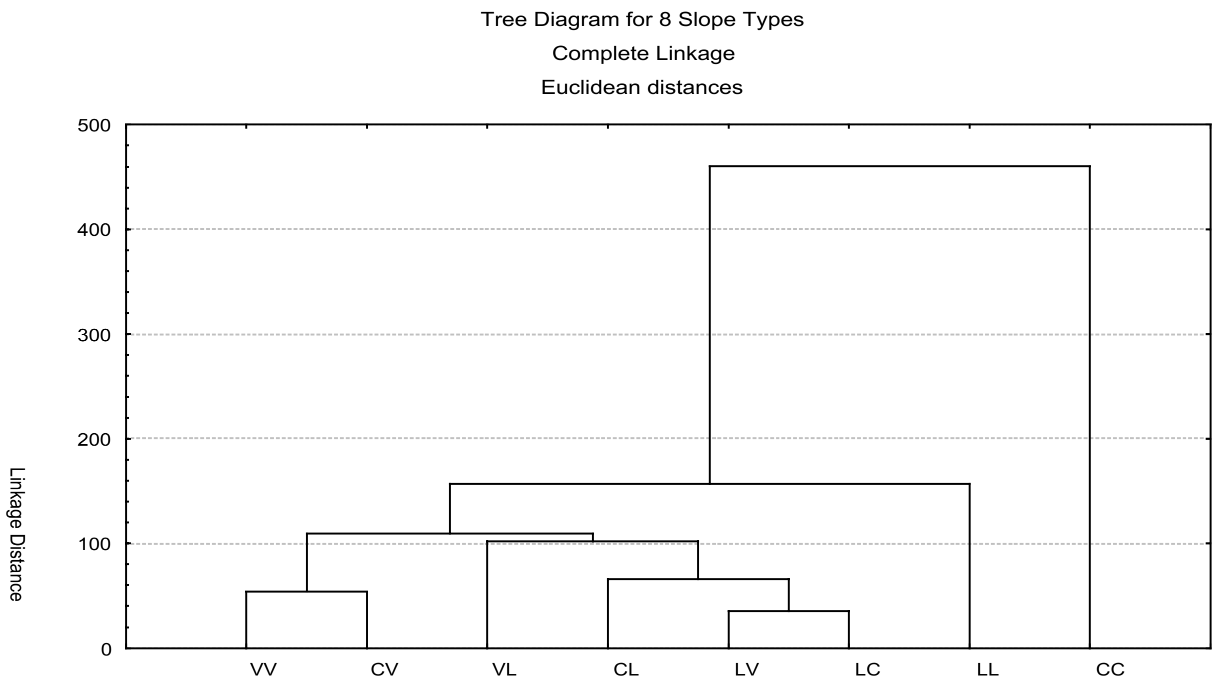

FIG. 8 - Tree diagram for the slope types.

far from landform presence and position on the slope. Slope type is nearer to landform presence and position on the slope than to lithology. It appears that in general land uses are linked to their variation in time, to the gradient of the slopes and to lithology. The fact that landforms are linked to the slope types can be interpreted referring to fig. 8 in which the tree diagram treating the slope types is presented. The «**cc**» slope type is quite far from all the other types. It is to be evidenced that the «**ll**» slope type stands alone far from the «**cc**» one and from the group that collects the other six slope types. In this group the «**vv**» and «**cv**» slope types are far from the group formed by the «**vl**», «**cl**», «**lv**» and «**lc**» ones. In general, the linearity of the slope is a result of human agricultural activities, the «**ll**» slope type represents the most anthropically affected one (by levelling and reshaping). The tree diagram resulted from the cluster analysis shows that the less anthropically influenced slope types («**cc**», «**vv**» and «**cv**») group by themselves.

In order to achieve information on the relationships among the variables linked in the fourth group of the dendrogram in fig. 7, a cluster analysis on land uses, with or without land use variations in the period 1976-1994, was carried out and the resulting tree diagram is shown in fig. 9. Land use variations are consequences of anthropic activities on the landscape. Three groups can be recognised in the dendrogram. A main group is formed by almost all the cases of land use without land use variations. A second group is formed by pastures and natural grassland, forested areas and arable soils, each with variations of land use; this group is clearly very far from the main group. A third group is formed by complex cultivation patterns with land use variations and olive groves and vineyards with and without land use variations; this group is nearer to the main one than to the second one.

In order to analyse the relationships between lithology and land use changes, the cluster analysis was carried out taking into account the different lithologies with or without variations of land use in time. The results are shown by the tree diagram in fig. 10. Four clusters can be recognized (tab. 12): the distances of each variable from the centre of the cluster are always small, showing the homogeneity of cluster itself. In cluster 3 it is to be noted the smaller distance of land use variations on **pa** (**pa**_with LUVar) from the centre of the cluster than those of the other two components, indicating a greater weight of lithology with land use changes in the cluster.

TABLE 12 - Within cluster distances of the variables forming the cluster expressed in fig. 10

Cluster 1	**pc**_with no LUVar		
Distance	0		
Cluster 2	ST_with LUVar		
Distance	0		
Cluster 3	**ps**_with no LUVar	**pa**_with no LUVar	**pa**_with LUVar
Distance	1.169	1.688	0.637
Cluster 4	**ps**_with LUVar	**pc**_with LUVar	ST_with no LUVar
Distance	1.545	1.528	0.967

CONCLUSIONS

Landscape sensitivity, as seen from the ecological point of view (Miles & *alii*, 2001), is an aspect of landscape ecology, when considered in holistic terms (Naveh & Lieberman, 1994). In this perspective the human footprint on landscape evolution is to be referred to as the quality and quantity of influence exerted. Levelling of the slope and land use changes exert a strong and sometimes not controlled impact on a landscape. This is much truer if the anthropic action is exerted on fragile landscapes. Our analysis of the changes of the landscape subjected to land use changes in the northern part of the Pliocene basin of the Asso River (Siena Province, Central Italy), carried out by adopting the landscape ecological analysis conceptual approach and methodologies, shows how strong and uncontrolled the anthropic impact was in the relatively short 1976-1994 time period taken into account in this paper. Aspects of this impact can be summarized as follows.

The bifurcation ratio applied to the basins on clayey and sandy sediments**,** of the first, second and third orders, characterized by linear «**ll**» slope type, gives higher values than those of the basins characterized by different slope types. Most of «**ll**» slope types pertain to first order basins, the smallest and easiest to be levelled. This fact confirms the effects of the anthropic action that led to the reshaping mainly of the convex-concave slopes to linear ones. The average length and slope gradient of «**ll**» slope types are the lowest and confirm the mechanical action for the levelling of the slope to achieve the optimal dimensions for agricultural uses.

To understand whether the human activities affected the slope orientations, circular analysis on data of slope aspects was used. The Rayleigh test of uniformity shows that generally no preferential slope aspect is evidenced. This means that the anthropic action did not choose preferential slope aspects by levelling and reshaping, perhaps because no very remunerative crop had to be cultivated.

The positions of the landforms on the slopes are ubiquitous, with the exception of the position on the backslope which is the least represented; this means that where the anthropic action is exerted, the backslope is preferred.

All over the studied area, land use changes led to an increase of arable soils and of pastures and natural grasslands of about 8 and 2%, respectively. Land use changes occurred with different evidence on different slope types and lithologies: mainly arable soils and pastures and natural grasslands increased their presence, either taking into account their distributions on the single slope type, either on the different main lithologies. On slopes on **pa,** land use variations occur whatever the slope gradient intervals are and regardless of the presence of the landforms. On slopes on **ps**, no variation of land use is found in presence of landforms, which are mainly represented by well developed *calanco, over* the slope gradient limit of 0.325.

The continuous reshaping and levelling of the slopes led to the decrease, all over the study area, of all the landform types, with the exception of *calanco* potential areas, that increased their presence, and of *balza*, that cannot rea-

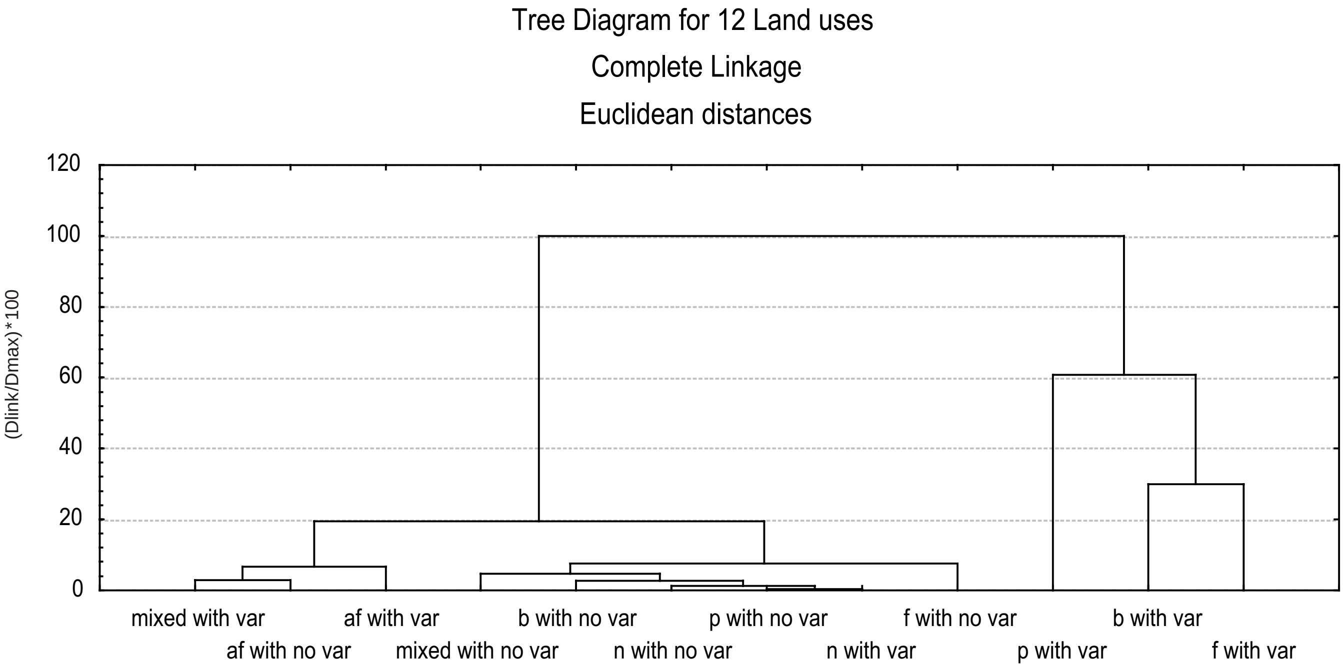

FIG. 9 - Tree diagram for land uses, with or without land use variations. «f»: arable soils; «b»: forested area; «af»: olive groves and vineyards; «p»: pastures and natural grassland; «n»: bare soil area; «mixed»: complex cultivation patterns. «with var» means that land use changes occurred; «with no var» means that no land use change occurred.

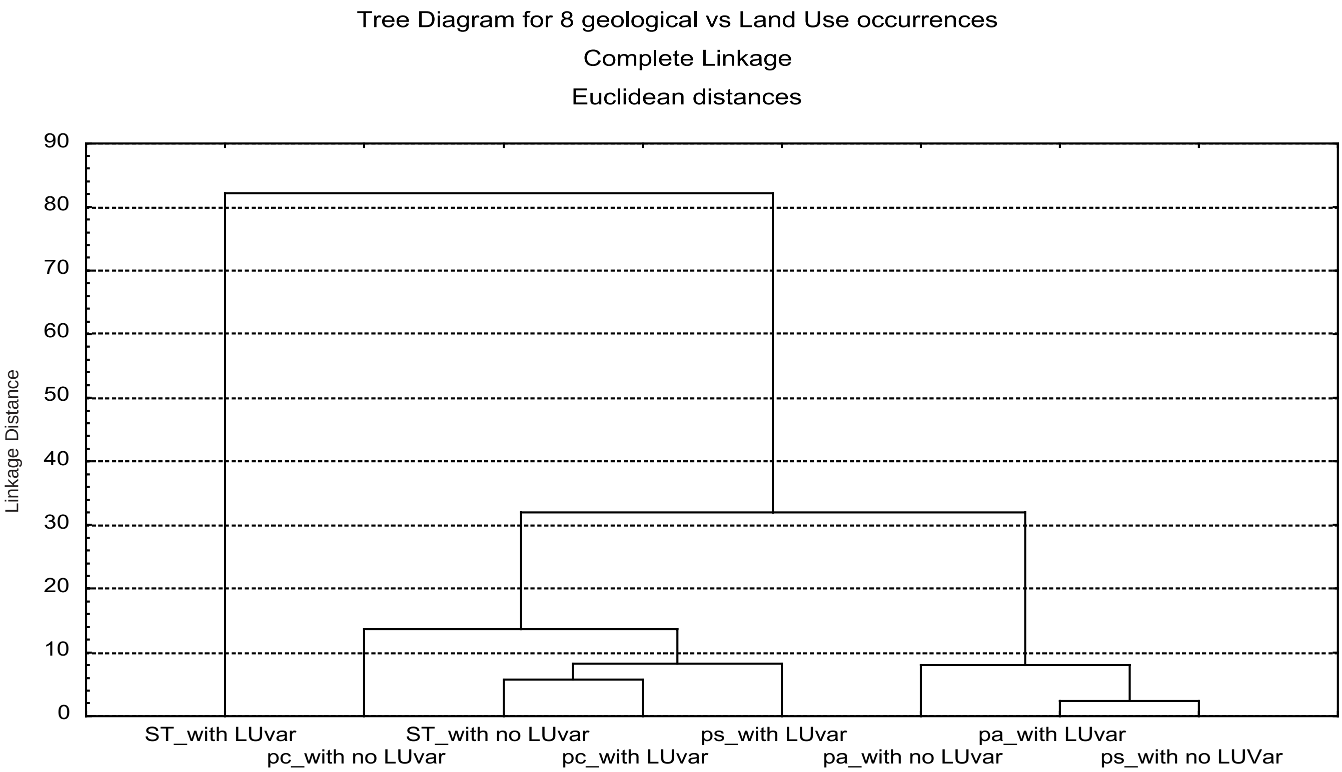

FIG. 10 - Tree diagram for lithologies, with or without land use variations. **pa** - pliocenic clays, **ps** - pliocenic sand, **pc** - pliocenic conglomerates. ST - Tuscan serie. «with LUvar» means that land use changes occurred; «with no LUvar» means that no land use change occurred.

sonably be affected by the anthropic action. The decrease of landforms is more evident on **pa**, on «**ll**» slope type. The increase of arable soils to the detriment of the other land uses, mainly of bare soil areas and of complex cultivation patterns, had as a consequence the inheriting of their landform distribution.

Cluster analysis on the 9 main landscape factors and characteristics led to the distinction of four clusters: the first one formed by slope length, the second one formed by slope height, the third one including landform presence and position on the slope and slope type; the last cluster is formed by land use in 1976, land use in 1994, land use difference in the time period, slope gradient and lithology. The fact that landforms are linked to the slope types can be better interpreted referring to cluster analysis treating the slope types, by which it is evident that the «**ll**» slope type stands alone far from the «**cc**» one and from the group that collects the other six slope types. In general, the linearity of the slope is a result of human agricultural activities, the «**ll**» slope type representing the most anthropically affected one (by levelling and reshaping). Besides this, the cluster analysis shows that the less anthropically influenced slope types («**cc**», «**vv**» and «**cv**») group by themselves. Land use changes are consequences of anthropic activities on the landscape. The cluster analysis on land uses, with or without land use variations in the period 1976 – 1994, led to the distinction between almost all the cases of land use without land use variations and those with variations of land use. The relationships between lithology and land use changes are not clearly distinguishable, even if the distances of each variable from the centre of its own cluster are always small, showing the homogeneity of the resulting clusters, while the distances among the clusters are much greater. In particular, the smaller distance of land use variations on **pa** from the centre of its own cluster than those of the other two components indicates a greater weight of this lithology in the cluster.

Cluster analysis confirms most of what highlighted by the aerial photograph interpretation and field surveys. The adopted methodology can be used in handling data for landscape analysis and in Geographical Information System applications and modelling, as statistical parameters and derivates show strong weights and linkages among the variables taken into account.

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