A hybrid land cover classification of landsat 7 etm+ data for an efficient vegetation mapping

Caprioli M., Leone A., Ripa M.N., Tarantino E.

in

Camarda D. (ed.), Grassini L. (ed.).
Local resources and global trades: Environments and agriculture in the Mediterranean region

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 57

2003
pages 451-460

A HYBRID LAND COVER CLASSIFICATION OF LANDSAT-7 ETM+ DATA FOR AN EFFICIENT VEGETATION MAPPING

M. Caprioli *, A. Leone **, M.N. Ripa **, E. Tarantino *
* Bari Polytechnic, 1th Engineering Faculty, Italy.
** Tuscia University (Viterbo), Agricultural Faculty, Italy.

ABSTRACT

Increasing population and urbanization have caused considerable impact on earth resources and environment. One of the critical aspects currently threatening the agricultural land-use systems in Mediterranean regions is the expansion of urban areas in productive agricultural lands and the related management problems of uncontrolled agricultural transformations. Population growth and massive migration from rural to urban areas has produced the loss of highly fertile agricultural lands. Moreover, this process is responsible for a more general deterioration of the relationship between the agricultural environment and the settled populations.

In multidisciplinary research contexts satellite remote sensing offers opportunities both to evaluate the effects of these processes and to provide one of the information layers needed for designing national agricultural strategies: obtaining accurate information on the earth's resources and monitoring changes are of paramount importance for sustainable use of our resources. In addition, such technology becomes an indispensable tool in territories where there is an evident lack of data bases for environmental monitoring in order to study local ecological cycles and to maintain bio-diversity.

This paper discusses a vegetation mapping methodology, applied to an optical sensors satellite imagery (Landsat 7 ETM+), using a hybrid approach in classifying vegetation species diversity of a study area (Lepini mountain chain in the Lazio region). Even if there are the spectral limitations of satellite imagery, the strength of this technology in predictive mapping can be made more effective using appropriate ground data.

A first step of this methodology is to determine the presence and the vigour of vegetation by NDVI (Normalised Difference Vegetation Index), in order to identify reduced or transformed agricultural productivity covers and reclaimed lands in the study area. Finally, a hybrid approach based on integrated unsupervised, supervised classifications and expert knowledge is adopted.

Keywords: agricultural and forestry land use systems; satellite imagery; hybrid classification.

1. INTRODUCTION

Land cover exerts a large influence on many basic environmental processes and consequently any transformation in it may have a marked impact on the environment al local to global scales, for instance it constitutes the greatest threat to biodiversity (Chapin et alii, 2000).

There are a number of ways in which scientific information required can be obtained, remote sensing being one (Townshend, 1992).

Remotely sensed satellite observations from space have fundamentally changed the way in which scientists study the atmosphere, oceans, land, vegetation, glaciers, sea ice, and other environmental aspects of the Earth's surface. In the past, the only way to investigate a given area was through direct observation and sampling on the ground and from ships or aircraft. (DeFries et alii, 1999).

Many portions of the globe are inaccessible and hardly known. Observations were mainly limited to those features that could be seen, photographed, or measured in visible portions of the spectrum. Local studies were compiled to provide regional interpretations of environmental conditions. However, it was difficult, if not impossible, to obtain global interpretations or to document changing conditions over large areas.

Remotely sensed satellite data and images of the earth have four important advantages compared to ground observations.

1. Synoptic view: Satellite images are "big-picture" views of large areas of the surface. The positions, distribution, and spatial relationships of features are clearly evident; patterns within landscapes, seascapes, and icescapes are emphasized. Major biologic, tectonic, hydrologic, and geomorphic factors stand out distinctly.
2. Repetitive coverage: Repeated images of the same regions, taken at regular intervals over periods of days, years, and decades, provide data bases for recognizing and measuring environmental changes. This is crucial for understanding where, when, and how the modern environment is changing.
3. Multispectral data: Satellite sensors are designed to operate in many different portions of the electromagnetic spectrum utilizing atmospheric windows. Ultraviolet, visible, infrared, and microwave energy coming from the earth's surface or atmosphere contain a wealth of information about material composition and physical conditions.
4. Low-cost data: Near-global, repetitive collection of data is far cheaper using satellite sensors than collecting the same type and quantity of data would be through conventional ground surveys (Verstraete et alii, 1996).

The archives of remotely sensed data acquired by earth resources satellite systems over the past three decades provide an unprecedented dataset for the study of land cover transformation. However, those interested in acquiring information on land cover and its transformation using remotely sensed data must consider a number of issues, not least the identification of the most appropriate dataset(s) for the task in hand (Franklin et alii, 2002). Currently, remotely sensed data for the study of regional and global scale environmental change are available from a multitude of sensors. Each has its own intrinsic characteristics (Lillesand et alii, 2000) and so the choice becomes more challenging since these characteristics determine the suitability of the dataset for a particular task.

Once a dataset has been identified, the method of extracting the information on land cover and its transformations must be considered, because the accuracy of the final data processed may be a function of the method used.

Many approaches are available. Commonly, techniques that include a range of statistical, structural and neural approaches are used. Particularly useful are integrated strategies of classification, especially when information on land cover transformation is necessary in order to evaluate the effects of these processes and to provide one of the information layers needed for designing national agricultural strategies.

This paper proposes a vegetation mapping methodology applied to an optical sensors satellite imagery (Landsat ETM+ sensor data), using a hybrid approach in classifying vegetation species diversity of a study area. Even if there are spectral limitations of satellite imagery, the strength of this technology in predictive mapping can be made more effective in using appropriate ground data.

As a first step of this methodology is to determine the presence and the vigour of vegetation by NDVI (Normalised Difference Vegetation Index), in order to identify reduced or transformed agricultural productivity covers and reclaimed lands in the study area.

Finally, a hybrid approach based on integrated unsupervised, supervised classifications and expert knowledge is adopted.

2. THE STUDY AREA

Lepini mountain chain (southern Latium, between the provinces of Frosinone and Latina, fig.1), has a geographical disposition from North-West to South-East. The northern part forms a sort of plateau weakly dissected by ephemeral channels, with altitude over 1000 m above sea level. The southern part presents higher relief, culminating with the Semprevisa Mountain, over 1600 m on sea level. Rocks are calcareous in the while area and this sharply influences hydrography, always ephemeral, due to typical calcareous rocks fractures. The Lepini geology is completed by pyroclastic deposits (prevalently tuffs) that, about one million years ago, overwhelmed calcareous rocks. Then, generally, the top of mounts and hills (up to 500-800 m above sea level) are calcareous, the valley are igneous rocks, often with younger alluvial fan and colluvial deposits.

The climate is generally sub-humid, due to abundant mean yearly rainfalls (1200-1500 mm/year), but monthly rainfall distribution is typically Mediterranean: only one peak in autumn and a minimum in summer, reflecting the important influence of the sea, only about 25 km away. This influences the natural vegetation, which presents three fundamental sub-systems, depending on the topography and altitude:

– Higher mountains, with beech woods, mixed woods, oaks with chestnut potentiality, mixed oak wood, ilex grove.
– Higher hilly (pedmont valleys, west oriented), with beeches, mixed woods, oaks with chestnut and ilex potentiality, mixed oaks woods.
– Lower/higher hilly (east oriented), with beeches, mixed oaks woods, chestnut potentiality, serie del beech.

There is abundant and varied fauna.

The economic context is similar to other Italian and European situations, characterised by the concentration of people on the coast and plain zones (in this case in Latina or in Rome, about 150 km away). But people tend to come back, at least for holidays and, so there is an increasing demand for dwellings, not due to local inhabitants, but to people that buy holiday houses in the home lands and towns. Other typical characteristics are:

– Aging population and, contemporarily, decreasing rate in birth and marriage.
– Tendency for emigrants to return.
– Presence of immigrants, close to national percentage and well going on the way to becoming part of the community.
– Decreasing number of people employed in agriculture and industry and increasing in services.
– Good availability of natural and cultural resources.

Concerning the agricultural and forestry systems, gross land use is: agriculture 53% (24% permanent, 29% annual), woods 22%. Agriculture is characterised by typical factors of economically weak systems: the farmers' age is relatively advanced, very frequently the property is broken up (2-3 ha is the average extension) and produces a trifling quantity (prevalently for the farmer and his family) and employs only family manpower, generally part-time. On the contrary, farm mechanisation is relatively high, but it is only a sign of abundance of supports for agriculture, not a sign of evolution, becoming, instead, an index of a wrong management of funds, not aimed at a real, well structured and, then, sustainable development. Tillages are prevalently cereals oriented, but arboriculture is also frequent (olive, above all) although in decline, while, in the past, it was fundamental for familiar agricultural economy.

Zootechnical systems are well developed, those relevant for mountain territory (above 400 above sea level) have an extensive character, focused on wild systems (bovine, goatish, ovine, swine). Forest clearings are largely preferred for pasture, but, generally, private properties are too small and since medieval times, there has been the Civic Use of land, which consists in the right to use the numerous and large public forests. But pastureland is very poor: soils are thin (because of heavy erosion) and, generally, biodiversity scarce, due to excessive grazing pressure.

Focus points of the forests systems are:

– Population is aging progressively, without younger return.
– Forestry jobs are scarcely attractive and suffer competition from other activities, also due to seasonality.
– Insufficient knowledge of woods resources and economic potentialities and consequently little possibility of exploiting the forest for services (tourism, culture etc.), alternative to wood production.

Geographical forest distribution is rather irregular, limiting factors are the thin soils of mountains tops and the frequent calcareous rocks emergences. In consequence, forest is more dense and developed where soils accumulate: in the valleys and where slopes changes (colluvial deposits).

From the floristic composition, the forest is not in a natural stage, being secularly influenced by anthropogenic factors (exploitation, logging, clearing etc.), but in recent years (practically with the landscape protection bill, n.431 of 1985) they were left undisturbed and now are evolving towards a natural cenosi. Forests are expanding also into abandoned agricultural and pasture lands and, so we can say that they are the more relevant element of this territory.

In synthesis, the Lepini mounts present a typical Apennine mountain territory, characterised by demographic and socio-economic marginality, since 60' and 70' of XX century.

2.1. The countryside and its background

A region has always been influenced by the historical events on its territory; this statement is particularly true for the area analysed in this work. For about seven centuries (from at least the 12th to 19th century) the most relevant activity for this area was sheep breeding, based on the method of transhumance. It is an old technique, practised since the Neolithic age, abandoned during barbarian invasions, after the fall of the Roman Empire (5th - 10th centuries) and reintroduced by Cistercian monks in the early Middle Ages. It consisted of the continuous moving of the cattle from the coastal plains (from Latina to the Maremma, whose mild temperature allowed winter grazing) to the Lepini mountains (but also in Abruzzo and Molise) during the summer, where the abundance of forage, scarce in the arid summer period, allowed the cattle to feed.

A direct consequence of transhumance was a precise landscape order, based on the pasture, i.e. on "open fields" (Sereni, 1989), indispensable because they allowed the sheep to feed freely. This implied a favourable situation for the long term, typical feudal system duration, based on the big land property of few barons. The consequence of this territorial order was uncertainty related to the "open fields" system, which limited any programming of land improvement (with rural buildings and other structures, land settlement etc.) aimed at a more productive agricultural development and, therefore, it did not permit the formation of a commercial middle class (bourgeoisie), interested in selling land products.

In this way, while in this area, as in almost all the Southern Italy, the feudal order protracted till modern times, in other European or Italian areas (such as Tuscany, that in Medieval times was involved in a similar social and territorial situation) urban settlement were dominating the landscape already at the beginning of the Renaissance and encouraging the economical evolution, "producing" a commercial bourgeoisie which lives in town, (the great innovative factor of feudal overthrow).

This feudal system produced a fundamental economic source for the Church Kingdom, assuring a relevant fiscal income with the so called "sheep duty", based on the right of pasture imposed on big landowners against an absolute property right for them and a fiscal taxation for the Church. It remained unchanged till the second part of 19th century, when the new Italian State acts abolished the enormous power (jurisdictional, administrative and political) of the barons and ecclesiastic landowners. The new acts gave shepherds and farmers the right to buy the assigned fields, the first step for a middle class development. Naturally, this process has not been harmful and without uncertainties and withdrawal of the evolution process (Sereni, 1989): the new middle class and the most active part of the old barons formed the new administration, it run the feudal overthrow in such a way that the effective changes were very small and the bourgeois substituted barons as big landowners of "close" fields, which replaced the ancient "open" fief, with a further disadvantage for the farmers and shepherds of loosing the right to use feudal lands, thanks to ancient *jus seminandi* and *jus pascolandi*.

In any case, agriculture remained marginal until the first decades of 20th century, when wetlands covering plain territories, where malaria decimated the people, were drained and reclaimed for agriculture and new farm-towns were established born (Latina, Sabuadia, Aprilia etc.). The "green revolution" of 1960 and 1970 completed the territory transformation, which meant also progressive marginality of mountain zones: the ancient systems, in fact, were, really, agro-forestry systems, with a perfect integration of agricultural, pasture and forestry activities, in a quasi-ecological system: cattle produced milk, cheese and meat (proteins) grazing in the woods and producing fertilizes (manure); tillage produced bread (carbohydrates) and vegetables; forests produced pasture, wood for buildings, agriculture apparatus and home heating. The present intensive systems are characterised by separation of subsystems, now impervious to each other: they receive outside energy and mass and do not need energy from the forests (due to mechanisation and new building construction systems) and fertilizers from cattle (due to mineral fertilisers).

So, it is necessary to look for and optimise a new role for the forests in the socio-environmental system and to consider forests pure ecosystems is a myth, because they were always human influenced. Consequently, forestry management aimed at stopping this decline and researching for new development is urgent. In this sense, focal points are:
– Reliability of plan proposals.
– Environmental sustainability of the planned development.
- Consequent detailed knowledge of natural resources and, first of all, vegetation knowledge by fast economic methods on a large scale.

The final aim of the work is researching for cheap, simple and fast ways to assess land cover and use. In this context, satellite imageries becomes an indispensable tool in territories where there is an evident lack of data bases for environmental monitoring, in order to study local ecological cycles and to maintain bio-diversity.

3. DATA AND METHODS

The data sources acquired for the analysis consists of:

- raster data of spectral bands 1 to 4 of Landsat-7 ETM+ (Figure 1a-1b) scene taken on 25 August 2000 for the test site of Lepini mounts in the Lazio region (Italy).
- training set and ground reference data obtained by land use survey (January 2002) and additional maps (Figure 2).

Landsat digital images, collected over a 25-year period, are among the most important data assets in the optical domain available to the earth-science community. The recent Landsat 7 (launched on April 15, 1999) carries an enhanced thematic mapper plus (ETM+), which should provide continuity of Landsat TM data with enhanced spectral and spatial resolution. The ETM+ detectors have demonstrated a stable radiometric response with low noise and few artefacts since launch. The USGS EROS Data Center (EDC) planned to collect 250 scenes per day in order to assemble a seasonal global archive of data. This will be the first systematic attempt to collect and archive space-based remote sensing to build a worldwide database covering key environmental features.

Fig. 1a-1b. Landsat ETM+ sub-scene enhanced in greyscale (a) and RGB modes (b) for the test site of Lepini mounts in the Lazio region (Italy).

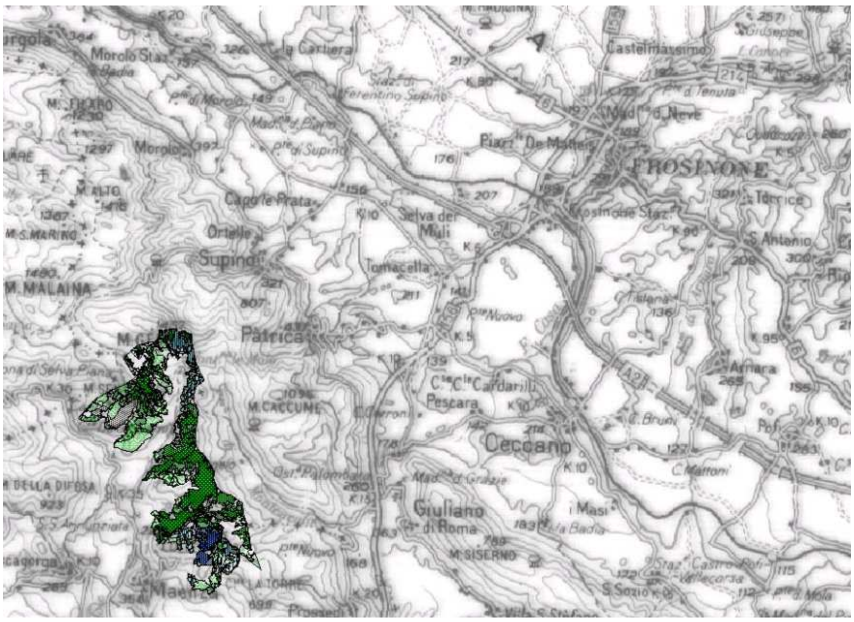

Fig. 2. Ancillary or external data from ground survey - Maenza (Italy).

3.1. The Normalized Difference Vegetation Index (NDVI) processed for the study area

The satellite data can be manipulated in order to define on the one hand biophysical indicators for the vegetation characterisation and on the other to classify species diversity in local vegetation. When remote sensing is used to recognise specific plants, as it appends in the case of agriculture and forestry, the problem to face is interpreting the reflected signal produced by the soil-plant-atmosphere system. In fact, the vegetation to be characterised, its underlying strata (such as soil, plant, plant litter, other types of vegetation, water, etc.), and the atmosphere interposed between the target and the sensor, all contribute to the sensor response. Since the plant leaves indicate the main part of the signal from vegetation, the spectral reflectance and transmittance of leaves are primary factors in understanding the reflectance of the full plant canopy. The knowledge of differences in leaf reflectance is considered a useful starting point to discriminate between vegetation species using remote sensing.

Traditionally, vegetation monitoring by remotely sensed data has been carried out by means of vegetation indices, which are mathematical transformations designed to asses the spectral contribution of green plants to multispectral observations. Vegetation indices are mainly derived from reflectance data from discrete red (R) and near-infrared (NIR) bands. They operate by contrasting intense chlorophyll pigment absorption in the R against the high reflectance of plant materials in the NIR. Such is the case of normalized difference vegetation index (NDVI), that is defined as (NIR-R)/(NIR+R) and provides a proven measure of the amount of vegetation on the ground.

Empirical studies and simulations with radiative transfer model support the interpretation of NDVI in terms of fraction of photosyntetically active radiation absorbed by vegetation canopy, canopy attributes (e.g., green biomass or green leaf area index), state of vegetation (i.e., vegetation vigour or stress), and instantaneous rates associated with the activity of the vegetation (Asrar et alii, 1992; Myneni et alii, 1995). Higher values indicated higher concentrations of green vegetation. Lower values indicated non-vegetated features, such as water, barren land, ice, snow, or clouds.

In this study preliminary interpretation of NVDI values, as is underlined in Figure 3, had contributed to evaluate the state of vegetation vigour and to better identify the vegetated areas of the Lepini mountains, useful for the following phases of training in the classification methodology.

Fig. 3. The normalized difference vegetation index (NDVI) processed for the study area.

3.2. Digital Classification

Image classification is the process by which image pixels are grouped into classes with similar spectral attributes, and then each spectral class is assigned to an information class. Generally, similar spectral classes do not necessarily represent a single or even similar information classes. Classic examples include the grouping of urban and bare soil information classes into the same spectral classes. One objective of our method development was to reduce the potential spectral class/information class confusion, while recognizing that some degree of confusion is inevitable.

Traditional methods of image classification require varying degrees of user input and subjectivity. For this reason, two classification using the same image will rarely obtain identical results. Furthermore, comparison between the many published methodologies is difficult due to the effects of the study location, the size of study, the type and amount of reference data, and the methods of testing and reporting accuracy. The level of generalization is low between classification methods due to variations in imagery such as illumination (mainly due to topography), atmospheric effect, and land cover. There are, however, fundamental principles that can be applied across many classification efforts such as band selection techniques, objective clustering and classification algorithms.

Prior to classification using supervised classification techniques, the spectral classes must be identified. In many cases spectral training is the most substantial obstacle to traditional supervised classifications. Unsupervised classifications remove the operators burden of spectral class training by automatically grouping pixel based on user defined parameters and spectral statistics. This method also has drawbacks, such as *a posteriori* labelling of spectral classes by the analyst, which is time consuming and can introduce bias. In response to this operator overhead, numerous hybrid approaches have been devised that combine in some way both supervised and unsupervised approaches.

If satellite assisted land cover discrimination is to become an operational procedure, the repeatability and accuracy of image classification algorithms must be improved, and analysis time must be reduced. San MiguelAyanz and Biging (1997) compared five classification methods for mapping natural resources in Spain, including supervised, unsupervised and a multi stage approach. Their iterative method classified one or two classes at a time with the class that attained the highest average accuracy being masked, and the next iteration being performed on the unclassified part of image. If two classes obtained high average accuracy, then both were masked. The average accuracy was based on the average of the user's and producer's accuracy for these classes. A key component was that optimal band selection was carried out for each iteration to maximize spectral separability. The iterations continued until there was no real improvement in the accuracy of the cover types remained.

In this study an integrated approach comprised of unsupervised classification, supervised classification and introduction of human-knowledge from field experience was adopted for classification (Figure 4).

To facilitate integration of the Landsat-7 ETM+ and vector data it was necessary to register both data sets to a single map coordinate system (Mather, 1995), in this case UTM map projection and WG84, by identifying 30 common Ground Control Points (GCPs).

A high (3rd) order transformation for rectification (RMS value lower than 1 pixel) and a nearest neighbour resampling method on the image were executed, in order to consider relief of certain sub-areas and minor distortion of radiometric values in the row data respectively (Khan et al., 1995).

The scene was subjected to unsupervised classification using ISODATA classifier. Level-1 separation between vegetation and non-vegetation classes was done with considerable accuracy Then the images pertaining to vegetation and non-vegetation classes were taken separately for further levels of classification. Zeroing of the masked in and masked out areas alternatively do this. Supervised classification was done for separation between vegetation cover types at level II, while at the same level ISODATA classifier was also used for non-vegetation discrimination. Using maximum likelihood classifier, training sets were assigned to discriminate among eight vegetation classes (Figure 5). Human knowledgebased mask and information from ancillary data were introduced to separate the different types of forests (a priori knowledge). Controlled cluster techniques were used for further separations within non-forest classes. Previous works indicated that relatively little unique land cover information was derived by using greater number (Vogelmann et al., 1998). It was assumed that 100 clusters would be likely to capture most of the land cover separability. Then each cluster was judged for its origin and accordingly put under the same class. Purely separated clusters were then deducted from the image.

Once supervised classification has been conducted, manual modifications are relatively simple within the raster structure. Many rule sets based on if/then logic can be developed and tested. As an example of rule based modification, we used NDVI in conjunction with training data, obtained with ground survey, to classify canopy cover for forest and shrub types. This method is employed instead of supervised classification because of considerable variation observed in the training data for canopy cover.

The final step of the process concerned the addition of all the resulting classes into classification output. Image smoothing techniques was used in order to enhance visual interpretation.

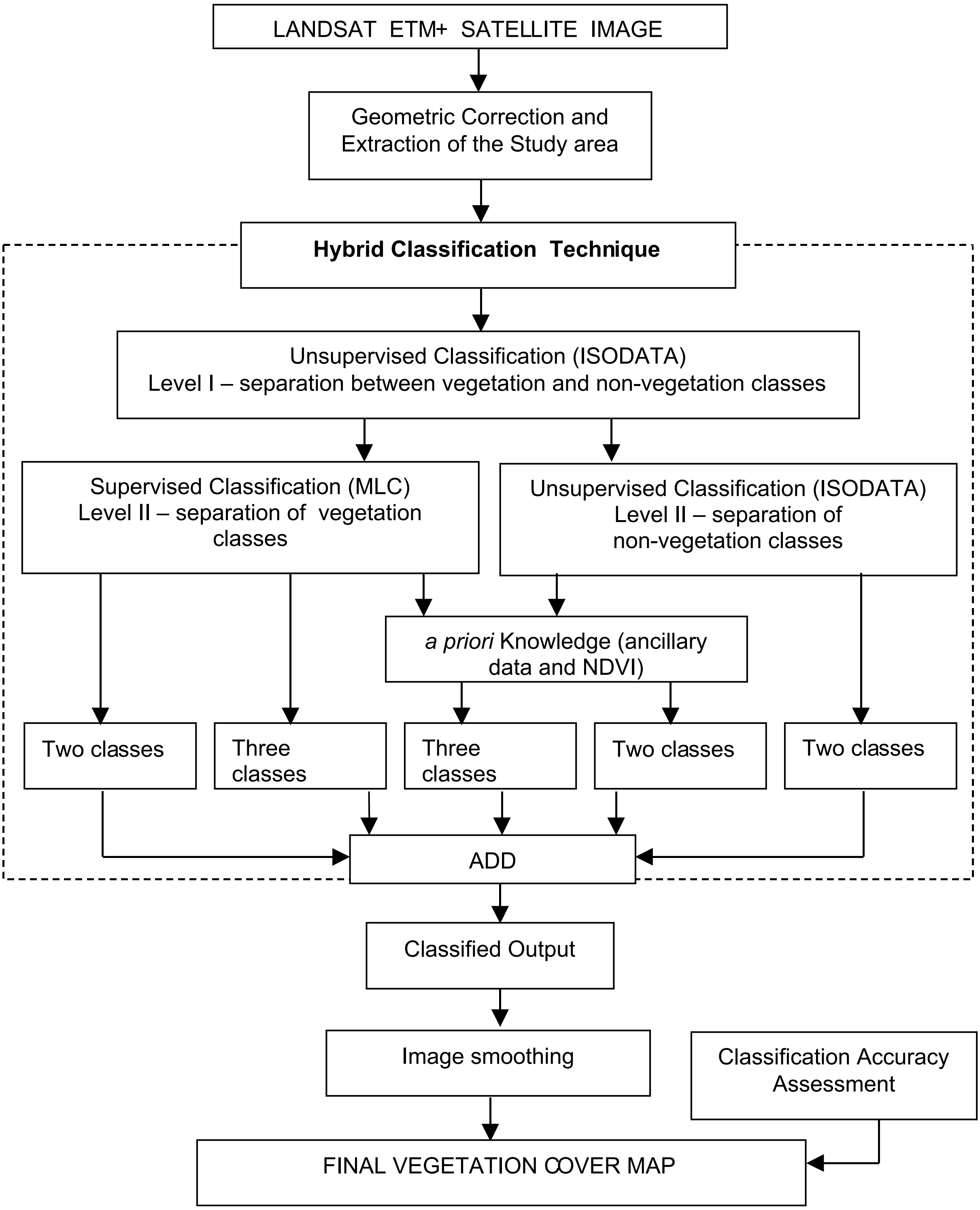

Fig. 4. Analytical sequence of vegetation cover classification procedure .

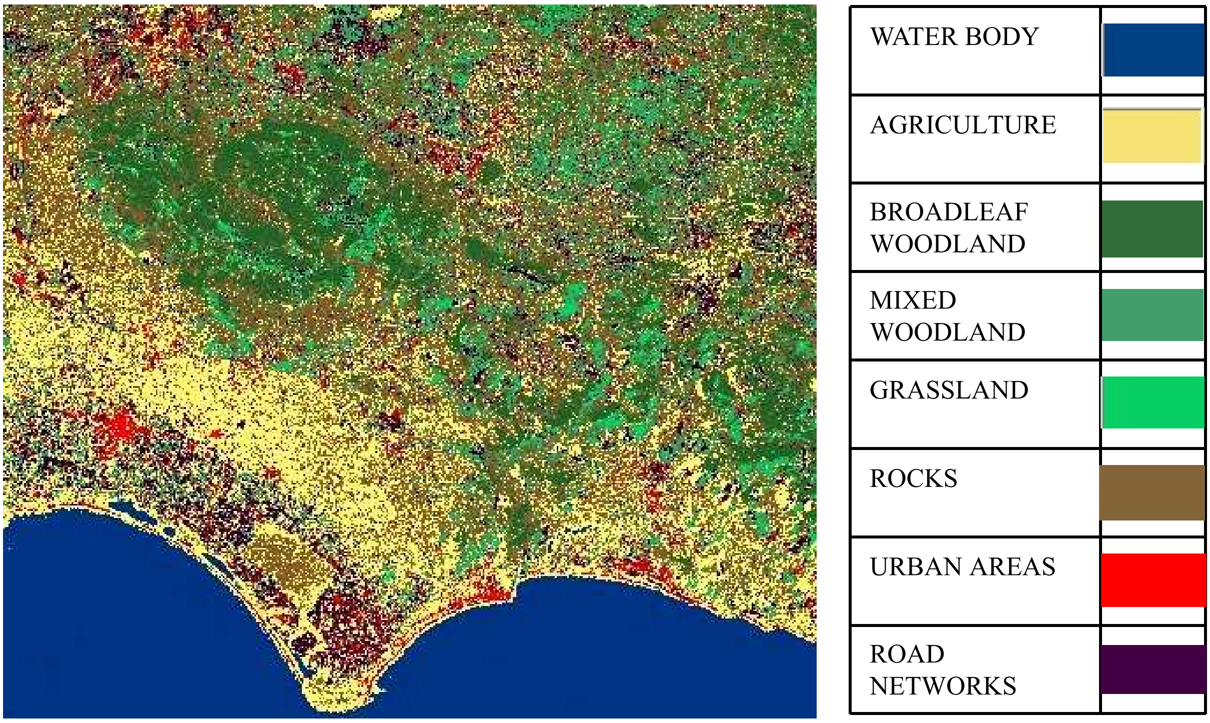

Fig. 5. Intermediate classification of study area with the identification of eight classes.

4. CONCLUSIONS

Uncontrolled agricultural transformations and urbanization have caused considerable impact on earth resources and environment. Consequently, forestry management aimed at stopping this decline and researching for new development is urgent. In this sense, focal points are:

– Reliability of plan proposals.
– Environmental sustainability of the planned development.
- Consequent detailed knowledge of natural resources and, first of all, vegetation knowledge by fast economic methods on a large scale.

The aim of this work is researching for cheap, simple and fast ways to assess land cover and use. In this context, satellite imageries becomes an indispensable tool in territories where there is an evident lack of data bases for environmental monitoring, in order to study local ecological cycles and to maintain bio-diversity.

This study demonstrates a vegetation cover mapping methodology that relates the reflectance information contained in ETM+ multispectral imagery to traditionally accepted ecological classifications. Remote sensing has demonstrated a significant contribution to vegetation mapping and to understanding of terrestrial ecosystem function, primarily through relationships between reflectance and vegetation structure.

The key element of the approach used here is the development of an hybrid classification system to achieve the goal of vegetation richness assessment and to derive more meaningful classes. With this methodology we really have observed a complex distribution of classes within the study area, with presence of erroneous or mixed pixels. This confirm our intention in developing an integrate procedure of classification in order to obtain more detailed and accurate results.

REFERENCES

Asrar G., Myneni R.B., Choudhury B.J. (1992), “Spatial heterogeneity in vegetation canopies and remote sensing of absorbed photosyntetically active radiation: a modelling study”, *Remote Sensing of Environment*, 41, pp. 85-103.

Chapin F.S. III., Zavaleta E.S., Eviner V.T. *et al*. (2000), “Consequences of changing biodiversity”, *Nature*, 405, pp. 234-242.

Congalton R.G. (1991), “A review of Assessing the Accuracy of Classifications of Remote Sensed Data”, *Remote Sensing of Environment*, 20(37), pp. 35-46.
DeFries R.S., Townshend J.R.G. (1999), “Global land cover characterisation from satellite data: from research to operational implementation?”, *Global Ecology and Biogeography*, 8, pp. 367-379.
Franklin S.E., Wulder M.A. (2002), “Remote sensing methods in medium spatial resolution satellite land cover classification of larges areas”, *Progress in Physical Geography*, 26, pp. 173-205.
Khan B., Hayes L.W.B, Cracknell A P. (1995), “The effects of higher-order resampling on AVHRR data”, *International Journal of Remote Sensing*, 16, pp. 147-163.
Lillesand T.M. and Kiefer R.W. (2000), *Remote Sensing and Image Interpretation*, 4th edition, New York, Wiley.
Mather P.M. (1995), “Map-image registration using least-squares polynomials”, *International Journal of Geographical Information Systems*, 9, pp. 543-554.
Myneni R.B., Maggion S., Iaquinta J. *et al*. (1995), “Optical remote sensing of vegetation: modelling, caveats and algorithms”, *Remote Sensing of Environment*, 51, pp. 169-188.
San-Miguel-Ayanz J., and Biging G. (1997), “Comparison of single-stage and multi-stage classification approaches for cover type mapping with TM and SPOT data”, *Remote Sensing of Environment*, 59, pp. 92-104.
Townshend J.R.G. (1992), “Land cover”, *International Journal of Remote Sensing*, 13, pp. 1319-1328.
Vertracte M.M., Pinty B., Myneni R.B. (1996), “Potential and limitations of information extraction on the terrestrial biosphere from satellite remote sensing”, *Remote Sensing of Environment,* 58, pp. 201-214.
Vogelmann J.E., Sohl T., Howard S.M., (1998), “Regional characterisation of land cover using multiple sources of data”, *Photogrammetic Engineering and Remote Sensing*, 64(1), pp. 45-57.