Remotely sensing data and thematic mapping for sustainable developing in Sperchios river basin (Central Greece)

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ABSTRACT

Policy and decision making in the context of sustainable development requires rapid, effective and efficient access to and integration of appropriate current information from a wide range of sources, including land cover changes information derived from remotely sensed data. Geomorphic factors, such as altitude, slope, aspect and lithology presented in the area comprise the main parameters, including the climate, influencing the distribution of land cover. The use of a Geographic Information System (GIS) allows further spatial analysis of the data derived from remotely sensed images and digital terrain spatial models, and analysis of the impact of land cover change on regional sustainable development. The remotely sensing data used in this study was Landsat 5 TM and Landsat 7 ETM+ images. Normalized Difference Vegetation Index (NDVI) and Selective Principal Component Analysis (SPCA) techniques were applied to detect land cover change and especially vegetation changes from multitemporal satellite data. The area under study is the basin of River Sperchios, which covers an area of some 1.780 km\textsuperscript{2}, is approximately 60-80 km long, 20-30 km wide with its southern and western flanks characterized by high elevations and steep slopes, whilst its northern flank presents lower elevations and more gently slopes. The conclusions obtained show that extensive land cover changes has occurred in the last decades as a result of both natural forces and human activities, which has in turn impacted on the regional sustainable development. The results thus provide very useful information to local government for decision making and policy planning.

Key Words: Landsat, NDVI, SPCA, Change detection, spatial models, sustainable development, Sperchios basin

1. INTRODUCTION

Land cover, i.e. the composition and characteristics of land surface elements, is key environmental information. It is important for many scientific, resource management and policy purposes and for a range of human activities. It is an important determinant of land use and thus of value of land to the society. Land cover change plays a pivotal role in regional and economic development and global environmental changes. These diverse roles were recognized by the scientists who paid much attention to the issues of land cover change over the past decade and a number of research works have been carried out by using various methodologies and algorithms to derive land cover and change information from different sets of remotely sensed data (Zhao et al. 2004, Harris 2003, Prakash & Gupta 1998). However, the complex component of geographic territory makes it difficult to develop a general method for all applications in different regions in the world. Furthermore, it is necessary to relate all the geomorphic factors, such as altitude, slope, aspect and lithology presented in an area, including the climate that influencing the distribution of land cover, so as to promote the contribution of these parameters to sustainable development.

In this work, multi-date Landsat images were analyzed and manipulated into a GIS environment to quantitative the width and distribution of land cover changes. The analysis covered a 15-year period during which a number of changes occurred in the study area. The distribution of land cover changes over an area and the relationship with the local lithology and the morphology using remote sensing data and Digital Elevation Model (DEM)-derived spatial models in a
GIS system is the main task of the present study. This relationship can help to a decision making plan which should lead to the sustainability of Sperchios’ river basin.

2. STUDY AREA

2.1 Physical Geographical setting
The basin lies between 38° 44’ and 39° 05’ N, and 21° 50’ and 22° 45’ N; the River Sperchios runs through this valley, which is a graben-like asymmetrical depression with an WNW-ESE direction, parallel to the active fault of Atalanti. The graben that covers an area of some 1.780 km² is approximately 60-80 km long, 20-30 km wide, having its southern and western flanks characterized by high elevations and steep slopes (Mt. Tymphristos 2.315 m and Mt. Iti 2.152 m), whilst its northern flank presents lower elevations (Mt. Othrys 1.720m) and more gently slopes. The main channel of Sperchios River flows from west to east receiving the fluxes from more than twenty major tributaries, with most of them, joining the R. Sperchios almost at right angles. The R. Sperchios has a mean annual water discharge of 62m³/s, varying between 110m³/s (in January) and 22 m³/s (in August) (Therianos, 1974). Flood events occur regularly exceeding the channel capacity. For example, on 29th June 1939 a flood discharge estimated at 800m³/s occurred, in response primarily to sudden snowmelt (Zamani & Maroukian, 1980). Furthermore, the total annual sediment load of the R. Sperchios has been estimated to be in excess of 1,5x10⁶ tonnes/year (Poulos, 1999).

2.2 Geological Setting
Maliakos Gulf, together with the valley of the River Sperchios, forms part of a tectonic trough which is controlled by major NW-SE and E-W trending faults parallel to Atalanti normal fault zone. The fault tectonism took place at the end of the Pliocene and beginning of the Pleistocene periods. The Pliocene deposits, located to the south of the Maliakos Gulf, have been uplifted by more than 500m. Furthermore, the mountainous region at the southern boundary of the River Sperchios’ catchment area was subjected to tectonic activity for a much longer period during the Quaternary; this has

![Digital Elevation Model (DEM) of Sperchios River basin](image)

Fig. 1: Location of the study area.
resulted in a vertical displacement of about 1.800m. The area experiences also strong earthquakes, like those which occurred in 426 B.C. and 1894 A.D. and induced big disasters in the broader area (Poulos et al. 1997, Pirazzoli et al. 1999).

In the drainage basin of River Sperchios, there are three distinct lithological regions (fig.2a) according to Ferrière (1977); these are:

(i) the western half is composed of Paleocene-Eocene flysch of the East Pindus and Parnassos (Iti) geotectonic zones; it is composed of alternating beds of argillite-siltstone-fine conglomerate and intercalations of shale. There is also a limited occurrence of pelagic and marly limestones of the Vardoussia zone in this area.

(ii) the south-eastern portion of the basin is composed of Middle Triassic-Jurassic massive dolomites and limestones of the Pelagonian zone; Upper Cretaceous flysch consisting of coarse sandstone alternating with shale and sandy marl belonging to the zone of Beotia; and Upper Cretaceous thinly-bedded limestones and Eocene flysch, composed of sandstone, clay and marl of the Parnassos geotectonic zone, and

(iii) in the north and north-eastern part, the lithological composition is completely different. Here, there is an ophiolitic complex in a shale-chert formation composed of shale, chert and limestone with ultra-basic and basic igneous rocks-peridotite, dunite, pyroxenite, gabbro, serpentine, diabase, olivine and metamorphosed green phyllite and schist; these belong to Maliakos (Subpelagonian) zone.

In addition, Neogene and Quaternary unconsolidated deposits occupy the central and lower (elevations <500 m) part of the elongated drainage basin of the R. Sperchios (Tripler et al. 1979, Maroukian & Lagios 1987; Gartzos & Stamatis 1996).

2.3 Soil types
The soil types were classified into five classes taking also into account the effect of mineral parent material and the geomorphology of the area, (Panagiotou 1974):

(i) Recent alluvial, are located at the center part of the valley,

(ii) Entisols (with a lithic subgroup) on limestones; (a soil group of azonal soils characterized by an incomplete solum or no clearly expressed soil morphology and consisting of freshly and imperfectly weathered rock or rock fragments),

(iii) Alfisols or Entisols on Flysch or Shale-cert and Ophiolite formation; (Alfisols are characterized of an ochric epipedon and an argillic horizon),

(iv) Inceptisols or Entisols (Psamments) on tertiary deposits,

(v) Entisols or Alfisols on flysch, slightly acids.

2.4 Climatic Setting
The climate of Maliakos Gulf and its surrounding area is a typical Mediterranean with dry periods in summer and early autumn and precipitation in winter and spring. Average monthly air temperatures are from 8° to 28°C and mean measured rainfall varies between 560mm/yr and 1750mm/yr depending upon the different altitudes; the later is associated with the amount of snow in higher altitudes (Stahl et al.1975, Kakkavas 1984). The most intensive rainfalls happen during the period from September to January and particularly during November. The predominant wind components are mostly from the east and west, following the localized east-west trend of the R. Sperchios valley. Average wind speeds are 1-2.5 m/s for the westerly winds and 2.5-4.5m/s for those from the east (Poulos et al., 1997).

3. DATA COLLECTION AND METHODOLOGY
3.1 Data set
The data used in the present investigation incorporates images from space-born and air-born earth observation systems, vector data and remote sensing and GIS techniques, including:

(i) Two Landsat 5 TM and Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images (7 spectral bands) were obtained covering the study area (path 184, row 034) dated 26th of July 1984 (free of cloud) and 28th of July 1999 (5% cloud cover); and,

(ii) High accuracy collection of 1997 orthorectified aerial photographs at 1m/pixel resolution used as the reference images for the geometric correction.

(iii) Topographic sheets of the Hellenic Military Servise-HMGS, geological maps of the institute of Geological & Mineral Exploration-IGME and soil maps were used.
Digital image processing of the satellite data was carried out using ERDAS IMAGINE v.8.6 and ILWIS v.3.2 software, while the manipulation of the spatial information and the digitizing of thematic maps were made using ILWIS 3.2 and ArcGIS v.9. Selected field checks were also took place in order to estimate the accuracy of the interpretation results. Field investigations were carried out to estimate the accuracy of the interpretation results. In this field visits a big fire event took place on August of 2000 was located and delineated using a Ground Positioning System (GPS).

3.2 Vector and raster data capture and processing

(i). Satellite data preprocessing
The preprocessing of the Landsat TM and ETM data was concerning the radiometric enhancement, by applying a linear contrast stretching and creating a new Look Up Table (LUT). Likewise, the images have been geometrically corrected by selecting a set of approximately 80 ground control points, derived from high accuracy aerial photographs of 1997 and topographic maps (1:50.000) of the Hellenic Army Geographical Service. Firstly, Landsat 7 ETM image was corrected and then Landsat TM scene was co-registered, using as a base the previous image. A Digital Elevation Model (DEM) was used for orthorectification of the two images and the nearest neighbour resampling method was applied in order to create the final images with 25 m ground resolution. The root mean square error ($r^2$) of the polynomial transformation (2nd order) was less than 1 pixel (0.54 for Landsat TM and 0.48 pixels for Landsat ETM image).

![Fig. 2: Landsat image in which appeared the burned area derived from the wild fire event occurred on August of 2000 near to the city of Makrakomi.](image)

(ii). Selective Principal Component Analysis (SPCA)
The change detection technique of selective principal component analysis (SPCA) was applied. This is a statistic technique of many variables, which chooses non-correlated linear compositions (eigenvectors) of variables in such a way that each output principal component (linear composition) shows the minimum variance. Additionally, their principal component axes correspond to uncorrelated data so it could be used as a data transform to enhance areas of local changes in multitemporal, multispectral images (Fung & Le Drew 1987, Mather 1999). Thus, from the registered Landsat subscenes the first four bands, of both dates, have been selected, in total 8 bands, to generate a new set of eight principal components. Here, the first component (PC1) corresponds to the brightness image (information concerning topography and albedo), while the second component (PC2) contain spectral information related with all kind of changes taken place during the period from 1984 to 1999 (fig.3a). The rest six PC’s contains a small amount of information relative to other applications and “noise”.

(iii). Vegetation index computation
The Normalized Difference Vegetation Index model used to compute the vegetation indexes in this study is that of Rouse et al. (1973):
\[ \text{NDVI} = \frac{(\text{NIR band} - \text{VIS band})}{(\text{VIS band} + \text{NIR band})} \]

\( \text{VIS} = \text{Visible band} = \text{band 3}, \text{NIR} = \text{Near infrared band} = \text{band 4} \)

These two bands are used to create a NDVI image for each period (1984 & 1999) using the method of dividing the pixel brightness of the two bands to produce a new image, method known as rationing. The new one is a black and white image where vegetated areas will generally yield high values because of the relatively high near-infrared reflectance and low reflectance in the visible band. In contrast water has larger visible reflectance than near infrared reflectance and corresponds to the very low pixel values. Rock and bare soil areas have similar reflectance’s in the two bands and result in vegetation index in low gray values. In order to be more familiar for interpretation the density slicing technique was applied on the NDVI image.

Finally, a NDVI-change image was generated by subtracting the two NDVI images of 1984 and 1999. For interpretation purposes the density slicing technique was applied on this image, in which the areas where vegetation has decreased appear in dark tones, while areas where vegetation has increased appear in bright tones. Unchanged areas appear in gray tones (fig. 3b).

(iv) The last step of image processing was the subtraction of the Principal Component 2 (PC2) and NDVI images so as to distinguish the changes of vegetation (cultivated land and natural vegetation) and other kind of changes due mainly to anthropogenic factors (fig 3c).

The visual interpretation of the change image PC2, the NDVI change image and the subtraction of these, showed up several temporal changes occurred in the coastal plain area, which are represented with different shades of grey, depending on the nature of each change. The most significant changes regard the cultivated areas, which were changed mainly from non-irrigated to irrigated crops (with high water demands). These changes are represented with white color and cover approximately an extended area of 42 km$^2$, while in black appeared the opposite change (from irrigated to non-irrigated crops) or set aside parcels that cover a very small area. As far as it concerns the appearance of natural
vegetation, which situated mainly at the hilly areas, the black color represents the reduction (mainly burned areas), while the whiter areas the increase of vegetation.

In the broader area of the city of Lamia the expanse of the urban shell appear very clearly with black color, mostly at the south and east part. Moreover, the appearance of grayish white areas along the sides of the Sperchios River banks indicate the decrease of the width of the river, due to reduction of water flux during the last two decades. Along the coastline only a few changes were detected. With black color is represented the erosion and with white color the accretion together with some shallow coastal areas. On the other hand, changes that derived from anthropogenic activities either along the shoreline or at the broader coastal plain area appear with black color. As regards the constructions along the coastline, these are located mainly to the north part of the Maliakos, near to the small port of Stylida. The human interventions in the broader coastal plain area are related to construction of roads, open mining and the widening of the existed drainage network extended to the south of the city of Lamia.

(v). DEM derived spatial models creation.
Initially, a Digital elevation Model (DEM) of the study area was extracted from the 1:50,000 scale topographic maps published by the Hellenic Army Geographical Service. The contour lines were digitized with an interval of 10-20 meters in the plain to 40 meters in the highland. Additionally, surface-specific point elevations, including high and low points, were digitized in order to improve the final digital product. A linear interpolation method was applied, based on the Bongefors distance method (ILWIS User’s Guide, 2001) aiming to the transformation of the contour data into a DEM, with a spatial resolution of 25 meters. With the intention of verifying its fidelity, the digital elevation model was plotted against to 1:50,000 scale contour maps, by interpolating the elevation values and overlapped onto the original topographic map. It showed a very good correspondence of the contour lines.

The DEM derived spatial models were obtained through the filtering of the DEM in order to create slope and aspect map and the classification of pixel values in the two maps according to their Digital Number’s table (Slope and Slope Aspect map, figure 3a & b accordingly). The slope map was created using the following classes: Flat-Almost flat areas from 0-3 degrees of slope, Gentle slope from 3-8 degrees; Moderate steep slopes from 8-30 degrees and steeply for the areas with greater than 30 degrees slopes (fig 4a & b).

(vi). Lithological map
From the unification of the lithological types (according to their lithological composition) a digital simplified lithological map of the area was created (fig. 5a).

(vii). Soil map
The soil map of the basin derived from the combination of soil types with the mineral parent material and the geomorphology of the area (fig. 5b).

Fig. 4 a & b: Slope and Slope Aspect map of Sperchios’ basin

(vii). Rainfall distribution map
Using the data of 10 well distributed meteorological stations of the study area the isohyets lines of the area was extracted and a rainfall distribution map was created by applying a linear interpolation method (fig. 5c).
4. GIS DEVELOPMENT AND MANIPULATION OF THE DATA

The work was conducted using a raster GIS for the operations. Generally raster GIS are easier to implement than vector GIS, they are also faster to use for many operations, specially where spatial precision is less important and data sampling is fairly uniform (Edwards 1991).

In order to determine the relationship between vegetation changes and geomorphic, climatic parameters that influence an area, the data were manipulated combining the NDVI change image with one of the other thematic maps each time. The Cross operation, concerns an overlay of two raster maps. Pixels on the same positions in both maps are compared; the occurring combinations of class name identifiers or values of pixels in the first input map. And those of pixels in the second input map are stored. These combinations give an output cross map and a cross table. The cross table also includes the number of pixels that occur for each combinations. The main restrictions in order to apply these techniques are that both input maps should have the same georeference and the output map uses the same georeference of the input maps. Four Cross images were created with the respectively tables. According to the values for the different units of the maps the results are as following:

1. Cross1 (NDVI change vs Soil map, based on lithological characteristics, fig. 6): The decrease of vegetation on recent soils lie on alluvial covers an area of 27.7 km$^2$, on Incepticols-Entisols lie on Tertiary sediments an area of 0.8 km$^2$, on Alfisols-Entisols lie on Flysch 26.5 km$^2$, on Alfisols-Entisols lie on Ophiolite and Shale-cert formation 5.1 km$^2$ and on Entisols lie on Carbonates an area of 8.7 km$^2$. On the other hand, the increase of vegetation on recent soils lie on alluvial covers an area of 82.1 km$^2$, on Incepticols-Entisols lie on Tertiary sediments an area of 1.3 km$^2$, on Alfisols-Entisols lie on
Flysch 41.5 km², on Alfisols-Entisols lie on Ophiolite and Shale-cert formation 18.7 km² and on Entisols lie on Carbonates an area of 8.1 km²

ii. Cross2 (NDVI change vs slope map, fig. 7): The decrease of vegetation on Flat-Almost flat slopes, covers an area of 28.3 km², on Gentle slopes an area of 5.8 km², on Moderate steep slopes 27.6 km² and on Steeply slopes 6.7 km². On the contrary, the increase of vegetation on Flat-Almost flat slopes, covers an area of 87.2 km², on Gentle slopes an area of 9.4 km², on Moderate steep slopes 44.2 km² and on Steeply slopes 10.5 km²

iii. Cross3 (NDVI vs Slope Aspect, fig. 8): The decrease of vegetation in the N facing slopes, covers an area of 4.5 km², in the NE, an area of 20.6 km², in the NW, an area of 13.1 km², in the SE, 11.2 km², in the SW, 8.2 km², in the E facing slopes, 2.9 km², in the S facing slopes, 2.7 km² and finally in the W facing slopes, 1.1 km². On the other hand, the increase of vegetation in the N facing slopes, covers an area of 10.5 km², in the NE, an area of 28.8 km², in the NW, an area of 20.5 km², in the SE, 22.8 km², in the SW, 22.8 km², in the E facing slopes, 7.5 km², in the S facing slopes, 10.8 km² and finally in the W facing slopes, 2.8 km²

iv. Cross4 (NDVI vs Rainfall distribution map, fig. 9): The decrease of vegetation in 400-600mm class, covers an area of 10.3 km², in 600-800mm class, covers an area of 24.3 km², in 800-1000mm class, an area of 18.3 km², in 1000-1200mm class, 7.5 km² and in 1200-1750mm class, an area of 7.7 km². Conversely, the increase of vegetation in 400-600mm class, covers an area of 47.4 km², in 600-800mm class, an area of 55.1 km², in 800-1000mm class, an area of 24.1 km², in 1000-1200mm class, 14.1 km² and in 1200-1750mm class, an area of 10.9 km².
Fig. 7: Cross2, NDVI change vs Slope map

Fig. 8: Cross3, NDVI change vs Slope Aspect map
5. RESULTS-DISCUSSION

The visual interpretation of remotely sensed data during the study period, showed up several temporal changes of land cover occurred in the basin, which are represented with different shades of grey, depending on the nature of each change. The most significant changes regard the cultivated lands, which were changed mainly from non-irrigated such as wheat to irrigated crops such as cotton and maze (increase of vegetation cover). These cultures have high water demands. These changes are represented with white color and cover approximately an extended area of 42 km², while in black appeared the opposite change, from irrigated to non-irrigated crops or set aside covering only a few areas. This kind of change shows the necessity for much more water supplies for irrigation use, which could lead to the perturbation of water regime of the area. Furthermore, the decrease of the annual precipitations during the last two decades (table 1) and the increased demands of water for urbanization purposes, make the issue of water supply balance very difficult for the next generations.

As far as it concerns the appearance of natural vegetation, which situated mainly at the hilly areas, the black color represent the decrease of vegetation cover, mainly burned areas, while the brighter areas the increase of vegetation. In the broader area of the city of Lamia the expanse of the urban shell appear very clearly with black color, mostly at the south and to the east. Moreover, the appearance of grayish white areas along the sides of the Sperchios River banks indicate the decrease of the width of the river, due to reduction of water fluxes during the last two decades. Along the coastline only a few changes were detected. With black was represented the erosion and with white color the accretion together with some shallow coastal areas. On the other hand, changes that derived from anthropogenic activities either along the shoreline or at the broader coastal plain area appear with dark tones. As regards the constructions along the coastline, these are located mainly to the north part of the Maliakos, near to the small port of Stylida.

The human interventions in the broader area are related to urban expansion especially in the broader area of the city of Lamia, construction of roads, the increase in open mining activity and the widening of the existed drainage network (like the spillway which discharge the big supplies of Sperchios in flash flood conditions). Geomorphic factors influencing ecosystems are essential. They include such elements as slope steepness, slope aspect and relief. Slope steepness acts indirectly by influencing the rate at which precipitations is drained from the surface. Slope aspect have a direct influence on plants by increasing or decreasing the exposure to sunlight and prevailing winds. Slopes facing the sun have a warmer, drier environment than slopes that face away from the sun. On the other hand, soils which determines the quantity and quality of the vegetation is directly related with the nature of the lithology presented.
The analysis of the cross maps shows that there is a high increase of vegetation on Alfisols-Entisols lie on Flysch formation and on recent soils lies on alluvial deposits and a decrease of vegetation in some other areas lie on Flysch leads to the result that these area are very susceptible to erosion and landslides. This phenomenon due to the nature of changes that are related with the increase of winter arable cultivations instead of summer which make more susceptible the bare soils in winter intense precipitations. Furthermore, the decrease of vegetation cover of cultivations that lie on Alfisols, which characterized of an argillic horizon demonstrate high risk conditions for landslides, especially when these cultivations are located in areas characterized of steep slopes and high amounts of precipitations. Moreover, the fire events took place in the last two decades and especially the one that was delineated on August of 2000 may lead to the deterioration of soil erosion and landslide which imply soil degradation of the area.

It is very interesting the presence and in some cases the increase of forest vegetation in the moderate and high steep slopes. This probably due, to the presence of flysch formation that usually generates rich autochthonous soils on steeply areas. Finally the eastern aspects of the slopes (SE and NE) represent the bigger proportion of vegetation increment probably because of the microclimate conditions and the fact that aspects facing the sun have a warmer, drier environment than aspects that face away from the sun.

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6. Conclusions

Land cover changes can impact ecosystems, environments and regional sustainable development directly and/or indirectly by affecting a wide range of processes. It is thus very important for decision making at local, national and regional scale to obtain real-time information on land cover and its temporal and spatial changes. Satellite remote sensing is an advanced technique for obtaining land cover dynamic information while a Geographical Information System is very useful to help analysts to carry out data management, manipulation and analysis. Selective Principal Component Analysis (SPCA) and NDVI subtraction techniques of Landsat images (1984 to 1999) provides an effective tool for the principal land cover changes detection information, because the areas of change appear clearly and can be monitored accurately.

Analysis of the land cover change information of the study area shows that a lot of significantly changes occurred during the period; in particular, extensive changes are related to agricultural land, such ass the winter arable land which changed into summer crops. This change probably is due to the regime of the subsidies that provided from the European Union the last two decades. Other kind of changes are related to the changes in natural forest vegetation mainly due to fire events, the urban expansion and finally changes due to anthropogenic activities like technical projects located in the coastal and plain area of the basin and open mining activities.

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References