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# Estimating land cover changes and associated environmental impacts on wetlands by coupling remote sensing and hydrological modelling

**ZACHARIAS IEROTHEOS, E. DIMITRIOU &
Th. KOUSSOURIS**
*National Centre for Marine Research/Institute of Inland Waters, Mavro Lithari,
GR-19013 Anavissos-Attiki, Greece*
thakis@ncmr.gr

**Abstract** Land-use changes and associated hydrological disturbances are common reasons for wetland degradation today. This necessitates the development of a method to identify and quantify potential ecological impacts from specific land-use alterations in order to avoid environmental deterioration. This scientific project used remotely sensed data, GIS techniques and hydrological modelling to estimate land cover modifications during a 40-year period, as well as associated changes in hydrological parameters, such as overland flow, soil moisture, evapotranspiration and water storage on the ground surface. Present and past land cover maps have been developed with the use of remote sensing and GIS software, and have been the basis of hydrological modelling simulations that indicate differences in these parameters during the study period. The modelling results illustrated significant variations in the hydrological regime caused mainly by the considerable increase of agricultural land and urban areas that posed adverse effects on the regional wetlands.

**Key words** land use; Greece; hydroecology; hydrological modelling; remote sensing; wetlands

## INTRODUCTION

Significant land cover changes have been observed during the last century, both spatially and temporally, mainly due to economic development and population growth. Between 1700 and 1980 there has been a 400% increase in cropland accompanied with a 30% decrease of forested areas, globally (Meyer, 1992). Such conversion of natural landscapes to agricultural, industrial or urban areas, has substantial impacts on regional hydrological characteristics including increased downstream flooding and decreased groundwater supply (Bhaduri, 2000; Rogers, 1994). Furthermore, human induced alterations in land use often comprise significant disturbances for the environment which may reach intensities that rival the most severe natural disturbances (Turner, 1993). In particular, as farms and urban areas replace forests and wetlands, water table lowering causing seasonally dry conditions may result in intermittent stream flow and therefore environmental degradation (Mitsch, 1993). Therefore, monitoring land cover changes and assessing their impacts is an essential task for sustainable environmental management and policy-making processes, while examining the historical pattern of an area's land cover changes provides the necessary context for modern ecological studies and designing conservation efforts (Foster, 1993).

State-of-the-art methodologies have recently been developed to enhance land cover change detection, including remote sensing and Geographical Information

Systems (GIS) techniques. Satellite imagery, nowadays, possesses the capacity to detect changes in land use on various scales and can also derive many biophysical parameters, allowing for spatial and temporal comparisons (Carlson, 2000).

This study attempted to conduct an integrated survey to identify land-use changes and related hydroecological alterations in a rural area during the last 40-years. A variety of hydrological and ecological parameters were analysed and their spatial and temporal alterations have been correlated to the observed land-use modifications in order to assess the impact of these modifications on the area's hydroecological conditions. This study has been conducted in an area with great scientific interest, the Trichonis Lake catchment, western Greece, where important land cover alterations have been observed during recent decades, coupled with substantial degradation of existing wetland habitats.

## SITE DESCRIPTION

The study area concerns an 88.2 $km^2$ semi-mountainous subcatchment of the Trichonis Lake basin, in western Greece (Fig. 1). This region incorporates significant water resources since it includes a large and deep freshwater body, Trichonis Lake, which has a surface area of 97 $km^2$, maximum depth of 58 m and whose potential water volume reaches approximately $2.8 \times 10^9$ $m^3$ (Dimitriou, 2001).

The geology mainly comprises flysch formations in the southern part of the area, containing sandstones and clayey schists which can be characterized as low permeability formations. Quaternary and Pleistocene sediments greatly affect the area's hydrological regime since they overlay flysch formations and facilitate the subsurface flow and the development of local aquifers due to their hydrogeological and geomorphic characteristics (low to medium permeability).

At the northern boundary of the subcatchment wetland areas are encountered with a variety of ecologically significant habitats including calcareous fens with *Cladium mariscus* and *Carex* spp. This wetland ecosystem is a priority habitat and is under protection and special consideration according to EU legislation (Natura 2000 Network).

Considerable stresses have impacted these wetlands during the last century, mainly due to land-use change including extension of the agricultural land towards the lakeshore, urbanization and deforestation (Georgiadis, 2000).

## METHODS

Two approaches have been used to achieve the predetermined aims. In the first phase of the study, remote sensing techniques were applied to identify and quantify the land cover alterations during the 40 years. In the second phase, the MIKE SHE hydrological model simulated the regional hydrology and estimated the associated changes.

### Remotely sensed data

Remote sensing techniques have been used to acquire the land cover data of the area and the ArcView 3.2 GIS program was used to enhance their processing and change

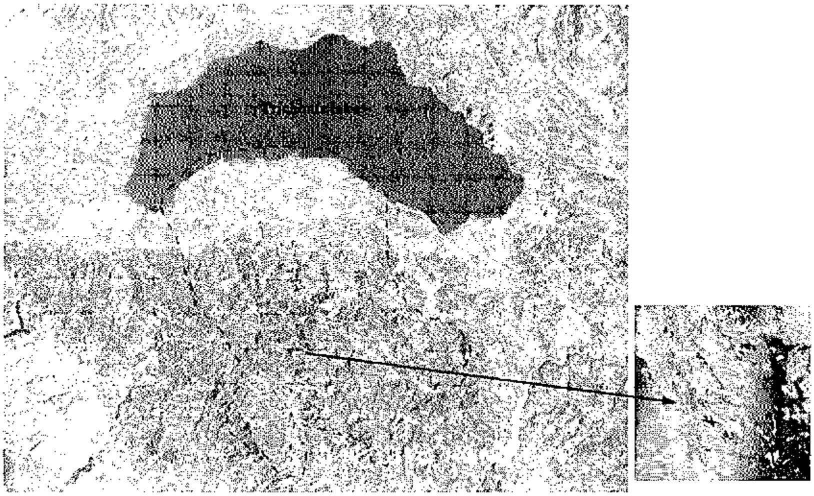

**Fig. 1** Satellite image of the subcatchment area.

detection analysis. In particular, two sets of aerial photos have been acquired from the Greek Military Geographical Service, for the years 1945 and 1986 (1:15 000 scale).

The procedure applied here to derive land-use maps and the respective changes on a spatial and temporal basis using remotely sensed data is widely used (Engmen, 1991; Weng, 2001) and comprises three stages:

In the *pre-processing stage* the images were enhanced by digital magnification (×2 times). The resulting photos were scanned at high resolution (1200 dpi) and imported in to ArcView software using the Image Analysis module for their elaboration. Reference points were selected and their coordinates identified from the area's topographic maps (UTM coordinate system) and assigned to both images using the Image Analysis package. This resulted in geographically rectified images.

The *image classification stage* included a supervized classification of the regional land cover based on the Land Categorization utility of the Image Analysis software and correction using recent land-use maps and ground surveys conducted by the study's scientific team. Six land cover categories were digitized in GIS polygons incorporating (1) wetlands, (2) agricultural fields, (3) forest, (4) grass/heather meadows, (5) urban areas, and (6) open water. The extent of each category was accurately quantified by utilizing the Spatial Analyst module of ArcView. The output from the *post-processing stage* comprised land cover maps for the years 1945 and 1986 that became the input to the MIKE SHE modelling software (through the MIKE GIS Interface).

## HYDROLOGICAL MODELLING

MIKE SHE is an integrated, physically based hydrological model that has been used in numerous hydrological and environmental applications worldwide, providing reliable and accurate results (Demetriou, 1999; Storm, 1995).

The modelling part of this study comprised five stages: (a) identification of the essential data and their acquisition, (b) pre-processing of the data ready to import in to the model, (c) model conceptualization and test runs, (d) calibration of the model, and (e) final simulations and post-processing of the results.

Two model simulations were set up, one for 1945 and one for 1986. The same meteorological and geological data were imported to both set ups but different land-use maps and soil data were used corresponding to the remotely sensed information provided by the results of the study's first phase. The simulated hydrological parameter variations, as illustrated in the two model output files, were compared and the estimated differences indicate the impacts from the land cover changes observed during the study period.

Meteorological data including rainfall, evaporation, solar radiation, barometric pressure, relative humidity, wind velocity and direction, air temperature (measurement period: 1989–1990) were acquired by a gauging network of five stations with a broad geographical distribution.

The regional geology was modelled by implementing a two-layer structure, selected after extensive simulation tests that indicated this particular set up as the most efficient for the modelling procedure. The first layer comprises a 3-m deep soil profile (unsaturated zone), over the second layer that consisted of flysch formations (saturated zone, average depth approx. 500 m) underlying all the rock formations encountered in this area. The hydrogeological parameters of these layers were estimated by *in situ* measurements and by recent studies conducted in this area (Dimitriou, 2001).

The actual evapotranspiration was estimated by the MIKE SHE model which utilizes the Kristensen & Jensen method with each time period's land-use map, potential evapotranspiration rate (calculated with the Penman-Monteith equation), as well as the associated vegetation database and dominant crop characteristics.

The grid geometry selected for the model conceptualization comprises 18 662 computation points in the saturated zone module with a grid dimension of 253 m, while the simulation covered a one-year period.

## RESULTS

### Land-use changes

The analysis and elaboration of the aerial photos and the existing land cover data for the years 1945 and 1986 provided the land categories, their extent and their respective changes during the time period examined (Table 1). The most significant estimated alteration is the decrease of wetland areas by approximately 71% from their initial extent in 1945; during the same period there has been a 17% increase of the agricultural land area which today covers 49.8% of the sub-basin area. The reasons for the wetlands' degradation are mainly the expansion of farming land (Fig. 2) and the progressive lowering of the lake's water level due to unsustainable water management practices. Another important aspect of the identified changes is that agricultural land presented a 6.2 km$^2$ increase (16.6% of the initial extent) during the study period while forests lost approximately 5.3 km$^2$ (11.6% of the initial extent) through deforestation practices for establishing farming areas. However, it should be stated that the forested area still remains relatively high compared to the other land categories since it covers 46.3% of the subcatchment area. This is probably due to the regional geomorphology, which is mountainous in the south and obstructs the development of cropland.

**Table 1** Land-use change in the Trichonis subcatchment between 1945 and 1986.

| | 1945 ($km^2$) | (%) | 1986 ($km^2$) | (%) | Change ($km^2$) | (%) |
|---|---|---|---|---|---|---|
| Wetlands | 1.27 | 1.46 | 0.37 | 0.42 | –0.90 | –70.87 |
| Agricultural fields | 37.20 | 42.65 | 43.38 | 49.74 | 6.18 | 16.61 |
| Forests | 45.66 | 52.35 | 40.36 | 46.27 | –5.30 | –11.61 |
| Grass/heather meadows | 1.76 | 2.02 | 0.12 | 0.14 | –1.64 | –93.18 |
| Urban areas | 0.79 | 0.91 | 2.99 | 3.43 | 2.20 | 278.48 |
| Open water | 0.54 | 0.62 | 0.00 | 0.00 | –0.54 | –100.00 |
| Total area | 87.22 | 100.00 | 87.22 | 100.00 | | |

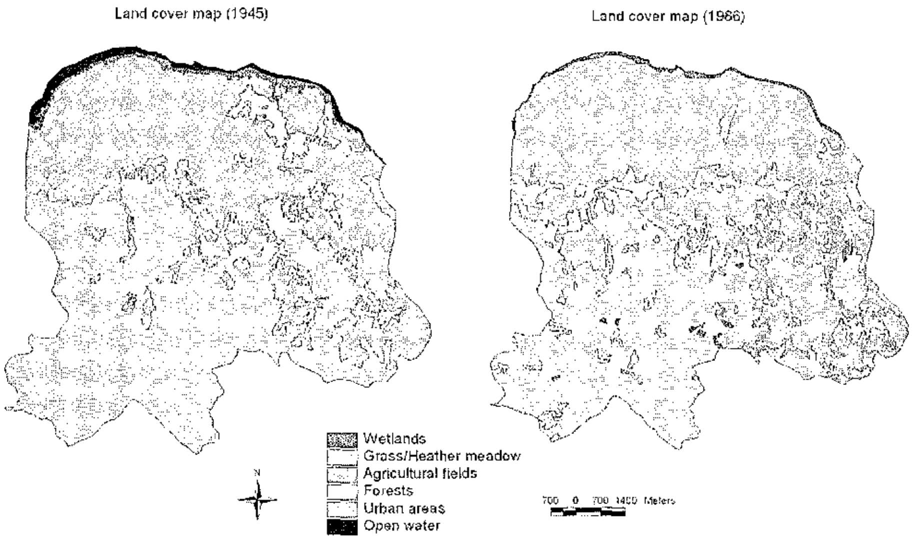

**Fig. 2** Land-use maps of 1945 and 1986 in Trichonis subcatchment.

Further, significant decrease has been recorded in the grass/heather meadows (from 1.76 km$^2$ in 1945 to 0.12 km$^2$ in 1986). These meadows were mainly used for stock-breeding and recently have been transformed to agricultural fields. The urban areas show the greatest increase in relation to other land cover categories, reaching an extent of 2.99 km$^2$ in 1986, from 0.79 km$^2$ in 1945 (279% increase). The proportion of the open water surface present in the 1945 land-use map (Fig. 2) has disappeared in the 1986 map because of artificial canal construction and other drainage schemes applied in the area that lowered the lake's water level significantly, as mentioned earlier.

## Hydrological alterations

MIKE SHE simulation runs indicated significant alterations of the hydrological regime between 1945 and 1986. In particular, the actual evapotranspiration increased from 525 mm year$^{-1}$ in 1945 to 557 mm year$^{-1}$ in 1986 (6.1% annual increase, Table 2, Fig. 3(a) and (b)). The seasonal evapotranspiration regime illustrates large rate increases

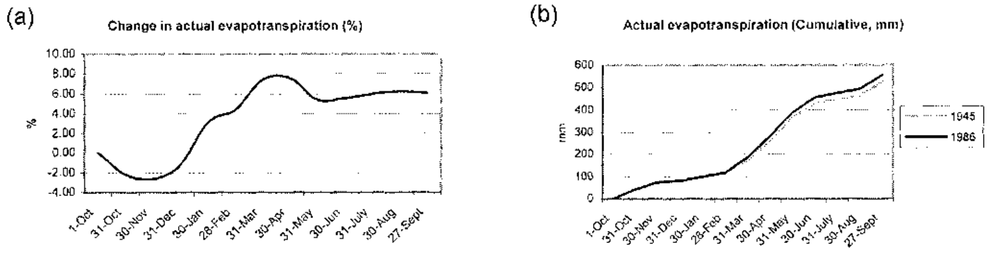

**Fig. 3** (a) Change in actual evapotranspiration between 1945 and 1986 (%). (b) Cumulative actual evapotranspiration (mm).

during warm months (March–August) of approximately 8%, while during the winter period the changes are relatively small (–3% to 5%, Fig. 3(a) and (b)). On a spatial basis, evapotranspiration reaches its maximum rate in farming areas during the summer period (0.24–0.27 mm $h^{-1}$), while in forests rates at present are 0.09–0.12 mm $h^{-1}$ and in urban areas, 0.06–0.09 mm $h^{-1}$. There is an obvious increase in the extent of areas of high evapotranspiration from 1945 to 1986, which is in accordance with the changes in agricultural land cover. During the winter period, the evapotranspiration pattern is different since forests presented the highest evapotranspiration rate in 1945 (0.008–0.01 mm $h^{-1}$) while cropland illustrated relatively low values (0.006–0.008 mm $h^{-1}$) and urban areas even lower values (0.002–0.004 mm $h^{-1}$).

The quantity of water stored on the ground surface has declined from 30 mm $year^{-1}$ estimated in 1945 to 27 mm $year^{-1}$ in 1986 (10% annual decrease, Fig. 4(a), Table 2). This is mainly due to the expansion of the agricultural land area which has increased water infiltration to the unsaturated zone and consequently reduced the amount remaining on the ground surface. Additionally, the agricultural development observed in 1986 resulted in increased evapotranspiration, according to the model's results, which further reduced the water available for storage on the ground surface.

The overland flow maps estimated by the model simulations indicate relatively higher values in 1986 than in 1945. The overland flow rates in most of the study area reach 0.0024 $m^3 s^{-1}$ in both years but lower runoff rates are estimated at the centre of the subcatchment in 1945 (approximately 0.0008 $m^3 s^{-1}$ lower than in 1986, 33% increase). This is expected due to the significant urban development during the last two decades which led to an increase of overland flow. Furthermore, low overland flow values (0–0.0016 $m^3 s^{-1}$) occur in the northern part of the sub-basin, where the wetland areas exist, during both time periods. This modelling outcome efficiently depicts the wetlands' physical conditions since in such areas subsurface and underground flows are the dominant hydrological phenomena, while large-scale water runoff is not expected. In 1945 the low overland flow zone was rather larger than in 1986 which implies a reduction of the wetland area during the examined period.

The water deficit in the unsaturated soil profile has increased by approximately 10.5%; 163 mm in 1945 and 180 mm in 1986, which is a significant hydrological alteration. The seasonal pattern of this alteration indicates a large decrease of the water deficit during the summer months and relatively small increase during the winter months (Fig. 4(b), Table 2). This pattern can be explained by the higher demand for

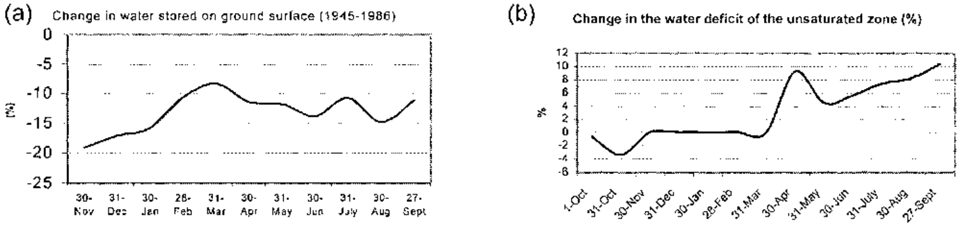

**Fig. 4** (a) Change in water stored on ground surface between 1945 and 1986 (%). (b) Change in water deficit of the unsaturated zone between 1945 and 1986 (%).

**Table 2** Hydrological parameters and their changes during the examined period.

| | 1945: (mm) | (%) | 1986: (mm) | (%) | Change: (mm) | % of the 1945 value |
|---|---|---|---|---|---|---|
| Actual evapotranspiration | 525 | 39.15 | 557 | 41.54 | 32 | 6.10 |
| Water stored on ground surface | 30 | 2.24 | 27 | 2.01 | –3 | –10.00 |
| Water deficit in the UZ soil profile* | –163 | 4.90 | –180 | 1.86 | –17 | 10.43 |
| Underground outflow | 784 | 58.46 | 772 | 57.57 | –12 | –1.53 |
| Overland outflow | 9 | 0.67 | 10 | 0.75 | 1 | 11.11 |

*Water deficit initial value is –155 mm.

soil moisture during the crop growth period of 1986 due to the expanded agricultural areas in relation to 1945.

## DISCUSSION

During the 40-year period examined for the Trichonis Lake subcatchment, a 16% increase of agricultural land against wetland and forest area was observed which lead to a 6% increase of evapotranspiration and 10% increase of the water deficit in the soil. This has serious implications for local water storages and their management since significant stresses are imposed due to the increasing agricultural water demands.

The 278% rise of the urban area has caused a 33% increase of the overland flow in these areas along with an 11% decrease of water stored on the ground surface. This is a significant alteration of the hydrological regime due to urbanization and is validated by the results of similar studies. In particular, Weng (2001) examined the impact of land-use and land cover change on surface runoff by comparing predicted runoff volumes in 1989 and 1997. That study indicated an increase in runoff volume by 8.1 mm during the 8-year period, mainly due to the observed urban growth. Bhanduri (2000) estimated an 18% increase in urban or impervious areas between 1973 and 1991 in the Little Eagle Creek basin, resulting in an estimated 80% increase in annual runoff volume. McCallum (1995) stated that as much as 50% of the land surface may become impervious to water infiltration in an urban catchment while the water excess in urban and suburban areas may affect the discharge profiles of water courses in a basin leading to increased erosion of stream banks and increased sedimentation (Boyle, 1997).

Water stored on the ground surface, which plays a very important role for the regional ecological status, has reduced substantially (to 11% of the 1945 value) due to increased water losses (increased evapotranspiration and water abstraction), and due to the highly modified soil conditions at the local scale (farming practices).

This study has shown that the methodology used, which incorporates multi-disciplinary and physically based scientific approaches, can identify and assess land-use changes on both a spatial and temporal basis and can, efficiently, quantify the associated alterations in hydroecological regimes. Furthermore, the results of such a survey can be very useful since environmental managers, policy-makers, scientists and local governments can use them for regional developmental studies as well as in designing protection and preservation measures.

## REFERENCES

Bhaduri, B., Harbor, J., Engel, B. & Grove, M. (2000) Assessing watershed-scale, long-term hydrologic impacts of land-use change using a GIS-NPS model. *Environ. Manage.* **26**(6), 643–658.

Boyle, C. A., Lavkulich, L., Schreier, H. & Kiss, E. (997) Changes in land cover and subsequent effects on Lower Fraser Basin ecosystems from 1827 to 1990. *Environ. Manage.* **21**(2), 185 -196.

Carlson, T. N. & Arthur, S. T. (2000) The impact of land use—land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective. *Global and Planetary Change* **25**, 49–65.

Demetriou, C. & Punthakey, J. F. (1999) Evaluating sustainable groundwater management options using the MIKE SHE integrated hydrogeological modeling package. *Environ. Modelling & Software* **14**, 129–140.

Dimitriou, E., Zacharias, I. & Koussouris, Th. (2001) Study for the water balance of Trichonis lake catchment, final report. In: Actions for the protection of calcareous bogs/fens in Trichonis Lake (ed. by I. Zacharias & Th. Koussouris), 111. Technical Report, NCMR/IIW.

Engmen, E. T. & Gurney, R. J. (1991) *Remote Sensing in Hydrology.* Chapman & Hall, London, UK.

Foster, D. R. & Zebryk, T. M., (1993) Long-term vegetation dynamics and disturbance history of a Tsuga-dominated forest in New England. *Ecology* **74**, 982–998.

Georgiadis, Th., Dimitrelos, G., Theocharopoulos, M., Chochliouros, S., Verios, G., Lambada, S. & Ceramonte, M. (2000) Study for the calcareous bogs/fens present state in Trichonis Lake. Final Report. In: Actions for the protection of calcareous bogs/fens in Trichonis Lake (ed. by I. Zacharias & Th. Koussouris), 24. Technical Report, NCMR/IIW.

McCallum, D. (1995) Trace metal dynamics and land use relationships in an urban watershed. MSc Thesis, Department of Civil Engineering, University of British Columbia, Canada.

Meyer, W. B. & Turner B. L. (1992) Global environmental change: a natural and cultural environmental history. *Global Environ. Change* **2**, 165–166.

Mitsch, W. & Gosselink, J. (1993) *Wetlands* (second edition). John Wiley & Sons, New York, USA.

Rogers, P. (1994) Hydrology and water quality. In: *Changes in Land Use and Land Cover* (ed. by W. B. Meyer & B. L. Turner), 231–258. Cambridge University Press, Cambridge, UK.

Storm, B. & Punthakey, J. F. (1995) Modelling environmental changes in the Wakool Irrigation District. In: *MODSIM 95, Int. Congress on Modelling and Simulation, Proceedings*, vol. 3, 47–52.

Turner, B. L., Moss, R. H. & Skole, I. L. (1993) Relating land use and global land-cover changes: a proposal for an IGBP-HDP core project. *Global Change Report, IGBP report no:24, HDP report no:25*, Stockholm, Sweden

Weng, Q. (2001) Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. *Environ. Manage.* **28**(6), 737–748.