Integrated remote sensing and GIS techniques for improving trans-boundary water management: The case of Prespa region

Marianthi STEFOULI[1], Eleni CHAROU[2], Alexei Kouraev[3], Alkis STAMOS[1]

[1] Institute of Geology and Mineral Exploration, 1 Spyrou Loui Str. 136 77 Acharnai, Greece, e-mail: stefouli@igme.gr, astamos@igmekoz.gr

[2] N.C.S.R. "Demokritos", Inst. of Informatics & Telecommunications 153 10 Agia Paraskevi, Attiki, Greece e-mail: exarou@iit.demokritos.gr

[3] CNRS / LEGOS-OMP, Avenue Edouard Belin 14, 31400 Toulouse France email: kouraev@legos.cnes.fr

Abstract: Various conventions have been established for the Protection and Use of Trans-boundary Watercourses and International Lakes which aim to strengthen national measures for the protection and ecologically sound management of trans-boundary surface waters and groundwater and establish concrete procedural obligations of cooperation between states for the protection and management of these water bodies. Main objective of this study is the assessment of the use of an integrated methodology, which includes remote sensing and GIS techniques for appraising the state of trans-national lake ecosystems. The Prespa region has been used as a pilot project region. It is situated in the Balkan Peninsula, in south eastern Europe, at the borders between Albania, Greece, and the FYR of Macedonia. Up to date information seems to be lacking or its access is difficult in the Prespa region. The methodology presented includes mapping and scientific processing and analysis of various data, and application of satellite image processing as well as radar altimetry techniques. The application of GIS techniques includes the formulation of a data inventory after the acquisition of topographic maps, compilation of geological, hydro geological maps based on analysis of relevant data and a digital elevation model. On the basis of available maps and digital elevation models the basic sub-catchments of the Prespa basin are delineated. A land use/cover classification for the broader area of the Macro Prespa lake is performed using Corine and ENVISAT MERIS Full Resolution data. Land cover changes are detected due to forest fires. Lake surface changes have also been assessed using multi-temporal Landsat images. The Macro Prespa lake has lost nearly 19 Km^2 of its surface due to a drop of the water level during the last 30 years. MERIS data have been used for the assessment of spatio-temporal variability of selected water quality parameters like turbidity, suspended solids and algae or chlorophyll concentration. An experiment has been completed for the characterization of the quality of water level time series reconstructed from sampled satellite measurements observed by TOPEX/Poseidon New Orbit (TPNO) and by ERS-2 / Envisat satellites for Ochrid lake. A temporal variability of median lake level has been constructed and this has been compared to in situ water level measurements. Temporal water level variability up to 3 m has been interpreted for Ochrid lake. Remote sensing provides valuable information concerning different hydrological parameters of interest to a transnational river basin assessment project. The methodology proved to be cost effective and if it is to be used in conjunction with in situ observations and hydrological modelling, these observations from space have the potential to significantly improve the understanding of hydrological processes affecting lake basins in response to climate variability.

Keywords: Remote sensing, GIS, water management, Prespa lakes

1 Introduction

Water resources management requires sufficient, long-term, frequent and reliable data. Over the last years, EO technology has developed to provide information that supports and complement ground information. Main objective of this study is the assessment of the use of an integrated methodology, which includes remote sensing and GIS techniques for gaining useful to water authorities information regarding

1. Catchment characterization after the extraction of selected hydrological parameters using a DEM and Land cover mapping
2. Surface water monitoring of lakes by estimating the surface area of lakes using multitemporal satellite images, the water level using Radar altimetry measurements, and the water quality parameters using MERIS Envisat satellite images
3. Supporting geology and ground waters surveys by photointerpretation of lineaments

The methodology includes mapping and scientific processing and analysis of various data, and application of satellite image processing as well as radar altimetry techniques. EO / GIS techniques have been used for the extraction of information in relation to the following:

MacroPrespa, Micro Prespa and Ochrid Lakes which form a unique ensemble of water bodies in the Balkan region (Fig. 1) have been used as pilot project area,. The Macro and Micro Prespa Lakes form the deep points of an inner-mountainous basin that has no natural surface outflow. Drainage is only provided through karstic underground links by which water of the Macro Prespa Lake (approx. 845 m asl) drains e.g. westwards towards the Ohrid Lake lying approx. 150 metres lower. On its northern shore, in the town of Struga, the Ohrid Lake has a natural outlet into the Crni Drim River. The Micro and Macro Prespa Lakes are connected in Greece via a small natural channel. From the North and East of the catchment, several small and mostly ephemeral watercourses flow into the Macro Prespa Lake. During the last century the Macro and Micro Prespa Lakes experienced significant changes in their water volumes.

A variety of remotely sensed and map data data have been analysed and integrated into the Geographic Information System (GIS). The analysis includes data from the Landsat, Envisat, ERS satellite systems. Different topographic, geologic maps of Greece, Albania, FYR of Macedonia of scale 1:200 000 and 1:50 000. Data published on the Internet such as the coastline of the Prespa / Ochrid lakes, the outline of the watersheds, the road / railway network, some major rivers, a few springs, major cities, some geologic and land cover information and a digital terrain model obtained from SRTM8-satellite data (Shuttle Radar Topography Mission (SRTM) of US NASA and German DLR) Integrated Image Processing and GIS techniques have been applied using the TNTmips software package. BEAM software has been used for the water quality assessments of the MERIS data.

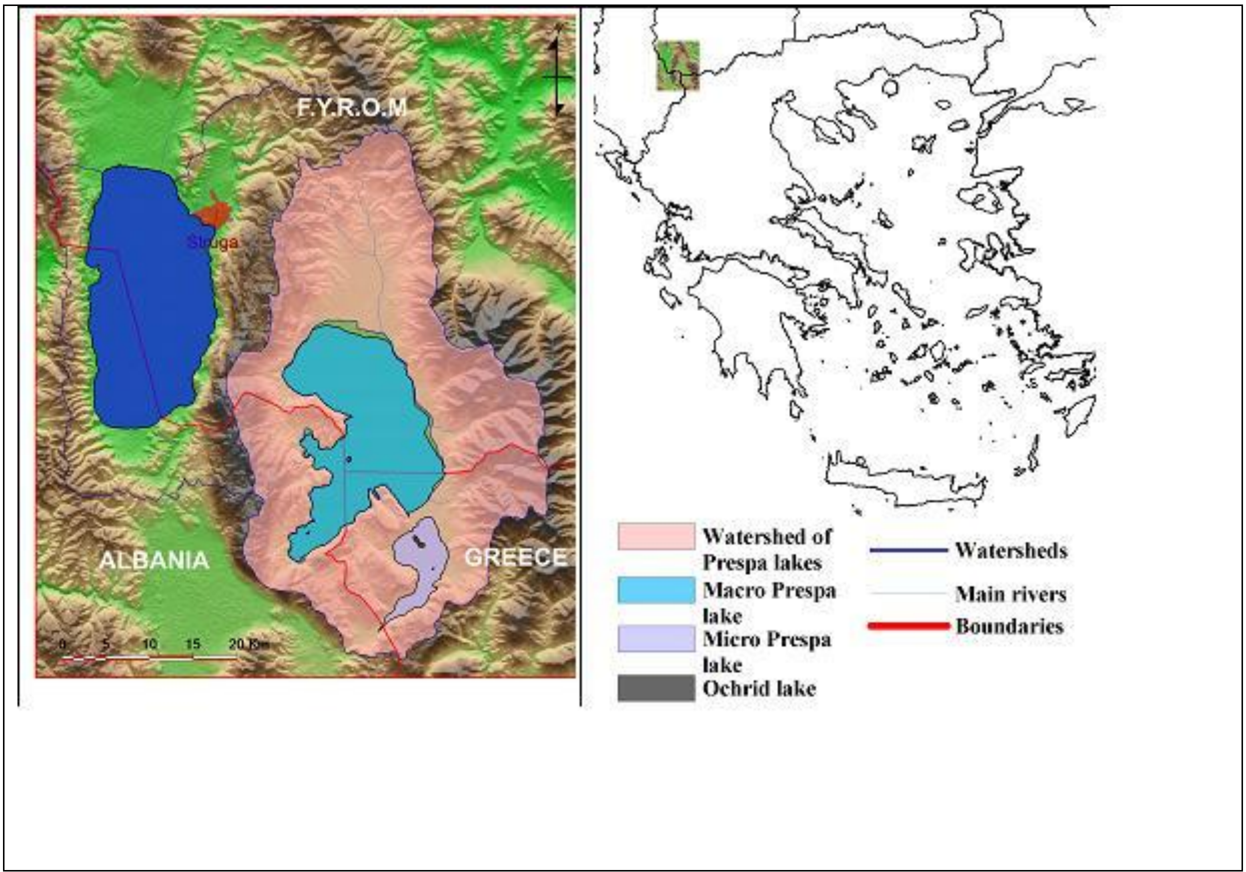

Figure 1 Pilot project area of Prespa / Ochrid lakes

2 Catchment characterization, Land cover mapping

EO-derived information such as land cover, moisture, rate of subsidence, DEMs (digital elevation models) or surface water variations can be used to analyze preferential aquifer recharge areas, groundwater proximity to surface, to infer properties of unconsolidated aquifers, or used in water cycle models (e.g. to calculate evapotranspiration).

Catchments of river networks are fundamental to the automation of flow-routing management in distributed hydrologic models and for the morphometric evaluation of river network structure.The analysis of the DEM resulted to the delineation of the hydrographic network. The following parameters are stored for each line of the drainage pattern in the GIS data base: The classification according to Horton, Strahler, Shreve, Scheidegger along with properties referring to Elevation drop, length, Average slope in degrees and Sinuosity ratio, Figure 2a. Generalization of catchments has been also obtained as each river network has been described by the various stream ordering procedures. Summary results for the watershed of Prespa lakes are shown on Table 1. For comparison reasons, the statisitics for Aghios Germanos catchment area are also included. Results are stored in the GIS database. The attributes table records a variety of derived hydrologic attributes of each watershed or basin. The table records for each polygon several simple attributes such as the number of streams (flowpath lines), total stream length in meters, and the average stream line length in meters. In addition, it records the more complex attributes, Table 1, (*http://www.microimages.com/documentation/cplates/73hydroCatchments.pdf*). The method focuses on the geometric aspects and does not touch the aspects of river or human interventions like the diversion of river flows. Nevertheless, detailed descriptions of both the catchments and river networks have been obtained. The ordering of the river network is satisfactory as far as the mountainous region is concerned. A key action that it is needed for qualitative improvement at the dataset level is the experimentation with higher precision and resolution DTM's.

WATERSHED	STREAM ORDER BY STRAHLER	NUMBER OF STREAMS	TOTAL STREAM LENGTH Km	AVERAGE LENGTH M	DRAINAGE AREA: Fill depressions Km^2
Prespa lakes	1 to Maximum 5	3459	4715.8	102.9	407

Table 1. Selected statistics for Prespa lakes watershed and Aghios Germanos catchments area.

Up to date information about land cover, land use, vegetation status and their changes over time (e.g. seasonally) is important for the understanding and modelling of hydrological processes such as infiltration, runoff rates, evapotranspiration and water needs. Space-borne sensors can provide such information, at different levels of spatial and thematic detail—resolution and number of retrievable land use classes (Giri et al. 2005; Carleer and Wolff 2006). The catchments of the three lakes have been described by the GIS based analysis of "Corine Land Cover Classification" Figure 2b. MERIS data has been used for Corine land cover map updating because of their improved temporal resolution. Burnt areas due to the 2007 forest fires are detected on the MERIS data (Figure 2b).

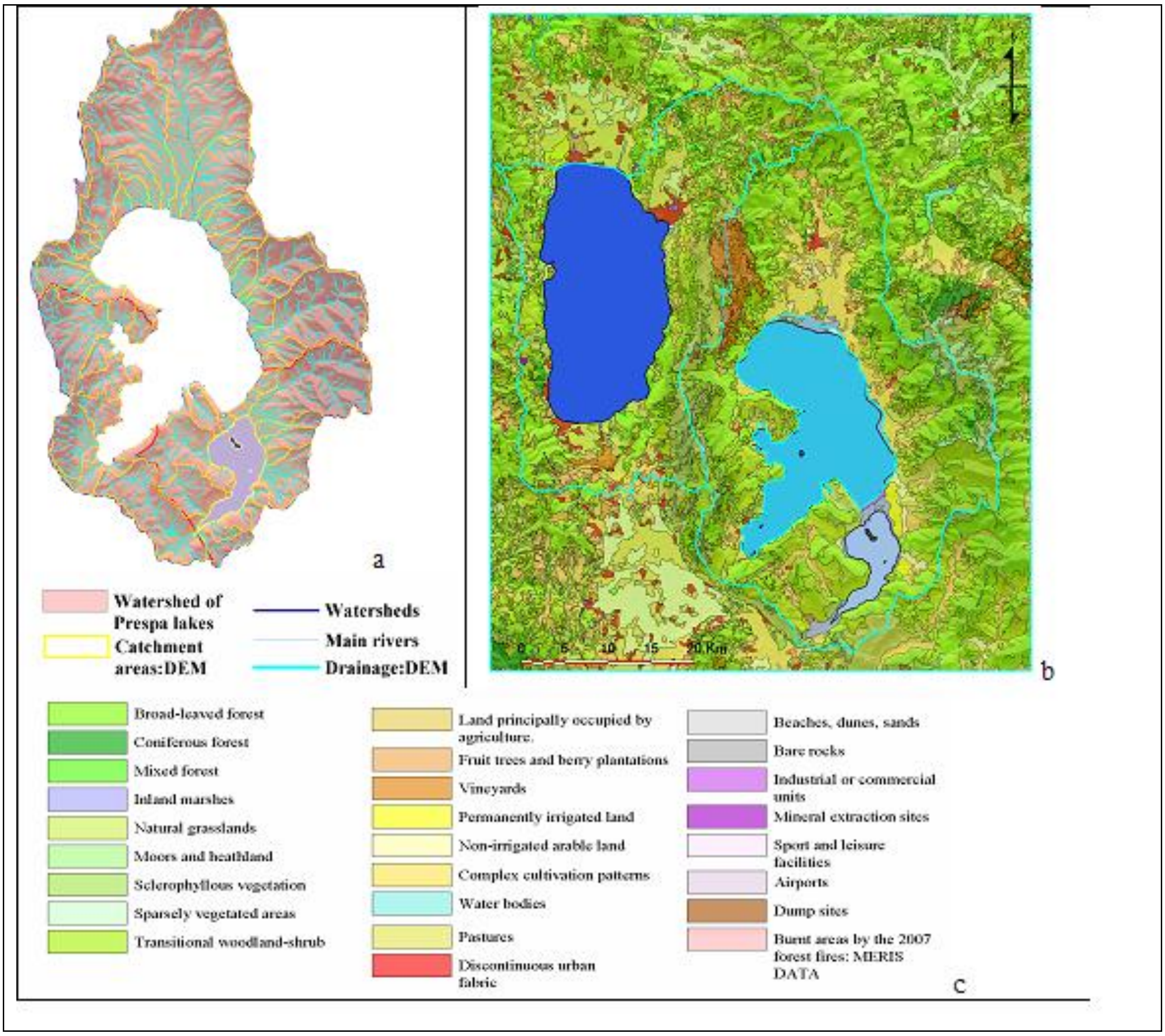

Figure 2 Catchments (a) and land cover map (b), legend (c) of the pilot project area.

The burnt areas identified on the MERIS data belong to the following level 3 Corine classification: Land principally occupied by agriculture, Broad-leaved forest, Mixed forest, Natural grasslands and Transitional woodland-shrub. The total burnt area is about 36 km^2.

3 Surface water monitoring

Delineation of water bodies is essential for the estimation of the water balance of the area. Water authorities need to know date, location, extent and variations of these water bodies; often inventories do not exist and updated information may be scarce or nonexistent. Landsat time series images have been used in order to identify the surface water of the lakes. A reduction of the surface area of Macro Prespa lake is evident, as estimates of its surface are as following: 1. November 1973 – 276.5 km^2 2. August 1988 – 273.7 km^2 3. August 2000 – 265.2 km^2 4.August - 2008 257.2 km^2. Macro Prespa lake has lost nearly 19.5 km^2 in the period 1973 to 2008. It is further evident that Macro Prespa lake is still loosing its surface in the period after 2000, even though the entire Prespa basin has been declared as a trans-boundary protected area, with the establishment of the "Prespa Park" by the Prime Ministers of Albania, Greece and the FYR of Macedonia on 2 February 2000.

Besides the water table?, space borne radar altimeters may provide information on average water levels with accuracy in the range of centimeters and ground resolution of some hundreds of meters (Berry et al. 2005).

The size of the lake and orientation of ENVISAT track make it possible to select sufficient number of altimetric observations for calculating lake level (Figure 3). Maximal possible number of 18 Hz observations for each cycle was 26. Figure 2 provides temporal variability of median lake level. Some cycles have less than 20 observations (they are marked as blue dots and are of lesser quality than the red dots (more than 20 observations per cycle). In the previous version of the time series (Figure 3), there were are three cycles (beginning of 2007) where level was too high. This was related with bad geophysical correction parameters, at the CTOH database. Now, after correct values have been introduced to the database, temporal level variability looks more reasonable (up to 3 m instead of up to 9 m). However, these data still need to be compared/validated with in situ data (if available)

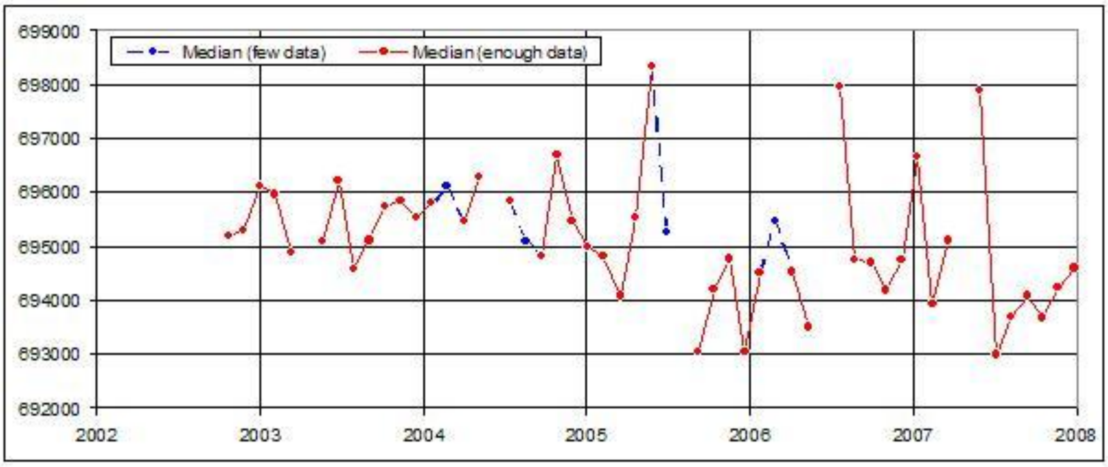

Figure 3 Median values of Ochris lake level from ENVISAT data (updated until cycle 64 - December 2007, too high values in the beginning of 2007 are now corrected).

Water quality parameters can be retrieved from EO data: this is of particular interest over transnational lake basins, which represent the main economic driver (e.g. fisheries industry, irrigation for agriculture) for the population. Parameters such as temperature, turbidity, suspended solids and algae or chlorophyll concentration can be monitored from space (Candiani et al. 2005; Sawaya et al. 2003). However, sensor resolution may hinder the retrieval of such parameters over small water bodies, and adequate in-situ measurements for calibration and validation purposes are needed.

4. Supporting geology and groundwater surveys

Groundwaters cannot be observed directly by existing EO satellites, however, location, orientation and length of lineaments can be derived from EO and can be used as input for studies of fractured aquifers (e.g. location of sites for water harvesting). Available geologic maps have been scanned, geo referenced, digitized for the whole region within the context of the GIS system Figure 3. The original maps have been of different scales and information content. The legend of all rock formations that it is stored in the database has been homogenised and is bilingual (English / Greek). The main rock complexes of the hydrogeology formations are the Quaternary, Neogene sediments, Mollase, Marbles and limestones, Metamorphic rocks, Basic rocks and Granites, Figure 3. In the Galicica area between the Macro Prespa and Ohrid Lakes, Mesozoic limestones are dominant. Furthermore, a great variety of rocks with varying age, genesis and lithology constitute the catchment area. Intensive tectonic implications result in the modification of the primary rocks and in the formation of very different structures and of a heterogeneous relief picture. Catchments can be described according to its hydro geological characteristics.

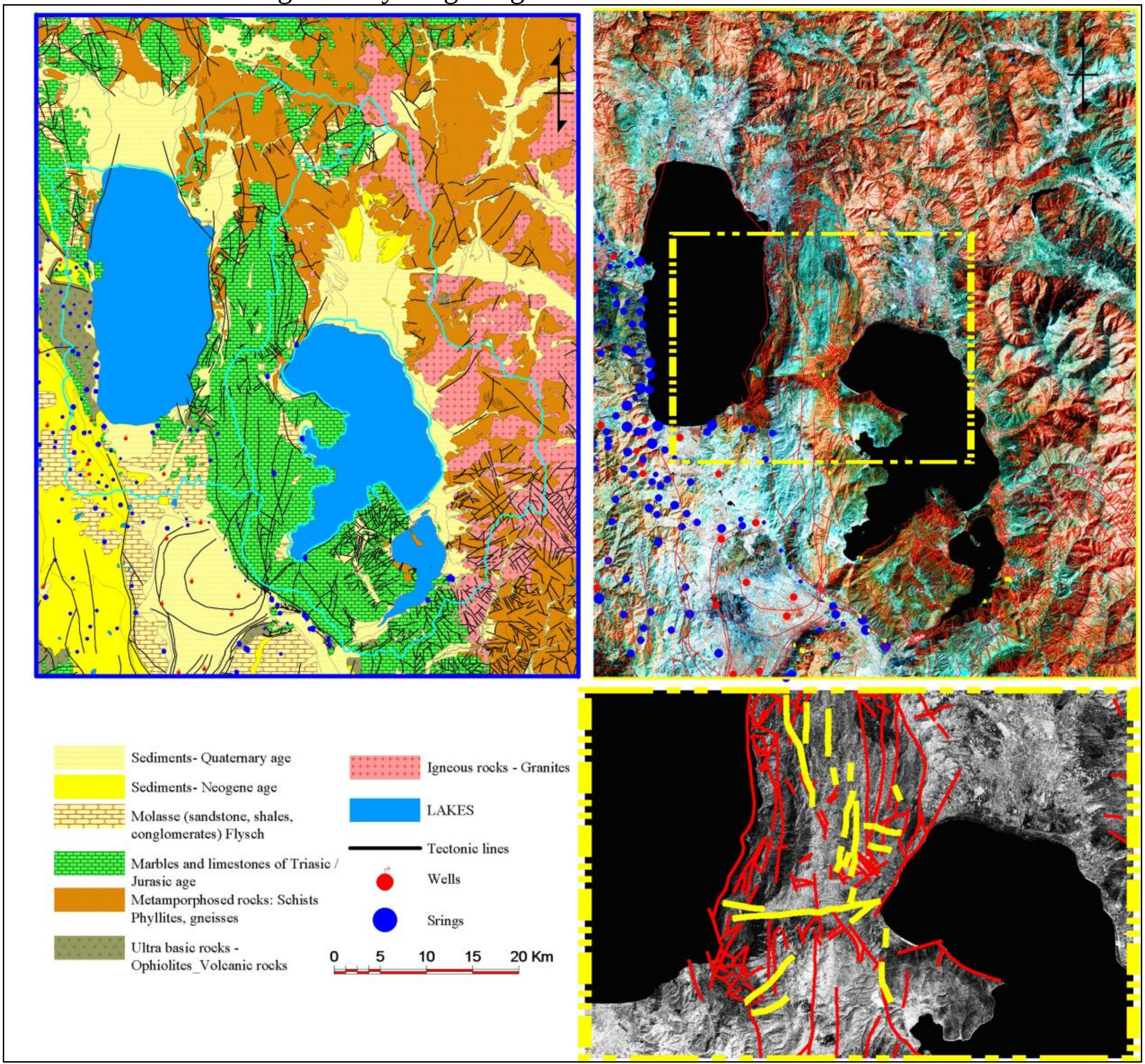

Figure 4 Geology and map update with interpreted lineaments shown on the Landsat image

Also tectonic features shown on the geology maps have been digitized. Due to the 3 different scales of the geology maps the tectonic lines visible is different in the various maps. Available information on location of springs has been also integrated in the GIS database. Lineaments of the fractured limestones have been mapped using the Landsat 2000 fused image product of the visible / infrared bands spectrals (30 m resolution) fused with the panchromatic (15 m). A sample is shown (Fig 4 bottom right), . Mapped lineaments on the satellite images may act as conduits for the confirmed water outflow of Macro Prespa to Ochrid lake as the location of spring outflows are related to the location of the faulting and satellite derived lineaments.

?Tables and Figures should be incorporated in text (Bonacci et al. 2008).

5 Conclusion

Earth Observation techniques can be used for monitoring selected parameters of transboundary lake basins. Results can be used to update the GIS database. Several parameters can be extracted and this includes description of catchments in relation to drainage networks, land cover, multi temporal surface area estimates of the lake water, water level, hydrogeology. The lakes can be also monitored for their water quality characteristics like total suspended sediments and chlorophyll content. The method is cost effective. Macro Prespa lake is in danger as it is loosing its surface water constantly for the last 30 years. Action should be taken in order to preserve these valuable lakes of Europe in terms of biodiversity.

Acknowledgments

This work is part of ESA Cat.-1 project no. 4864 entitled “Monitoring and assessing internal waters (lakes) using operational space born data and field measurements.” ESA is acknowledged for providing the MERIS data. The Society for the Protection of Prespa, Greece is acknowledged for providing lake measurements. This study has been supported and data have been provided by the working team of the “Sustainable management of the International waters: Prespa lake NATO SfP Project No. 98116

References

Giri, C., Zhu, Z. and Reed, B., 2005. A Comparative Analysis of the Global Land Cover 2000 and MODIS Land Cover Data Sets. Remote Sensing of Environment, Vol. 94, No. 1, pp. 123-132.

Berry PAM, Garlick JD, Freeman JA, Mathers EL (2005) Global inland water monitoring from multi-mission altimetry. Geophys Res Lett 32:L16401, DOI 10.1029/2005GL022814

Candiani G, Floricioiu D, Giardino C, Rott H (2005) Monitoring water quality of the perialpine Italian Lake Garda through multitemporal MERIS data, Proceedings of MERIS-(A)ATSR Workshop, Frascati, Italy, 26–30 September 2005, CD-ROM ISBN 92-9092-908-1 ESA

Carleer AP, Wolff E (2006) Urban land cover multi-level region based classification of VHR data by selecting relevant features. Int J Remote Sens 27(5–6):1035–1051

Sawaya KE, Olmanson LG, Heinert NJ, Brezonik PL, Bauer ME (2003) Extending satellite remote sensing to local scales: land and water resource monitoring using high-resolution imagery. Remote Sens Environ 88:144–156

Schultz GA, Engman ET (eds) (2000) Remote sensing in hydrology and water management. Springer, Berlin Heidelberg New York Töyrä J, Pietroniro A (2005) Towards operational monitoring of a northern wetland using geomatics-based techniques. Remote Sens Environ 97(2):174–191