Use of Earth Observation / Geoscientific Data and Web-GIS Techniques for Water Resources Management of Nestos River Basin

Marianthi STEFOULI, Eleimon TILIGADAS and Sotiria DEVENE, Greece

Key words: Hydrography, Transnational river basin, Geoinformatics, Remote sensing.

SUMMARY

The diversity of the natural heritage is one of the biggest assets of Rhodope region (Thrace, Nothern Greece) with a view to sustainable development. The water management practices for both quantity and quality control are not uniform along transnational regions. Different regulations are adopted by EU and not EU countries on how they would comply with the existing Water Framework Directive. Such is the case of water quantity/quality control by separate laws at different governments. Also the users are primarily concerned with the immediate geographic area and may be unaware of the effects of exercising their rights upon the other users who may be in border nations and may be themselves subject to different rules and regulations. The other dilemma is the intergovernmental conflict that may occur between state governments concerning interstate surface water and groundwater bodies.

Modern reality makes necessary the use of valuable information provided by the various remote sensing systems along with digital information systems, which are to act as effective tools for supporting decisions that are related to the management of water resources. Furthermore, the results should be communicated to decision-makers.

The Nestos river basin has been used as pilot project area of study. The objective of work has been to evaluate the use of integrated Earth observation and GIS techniques for the sustainable water resources management of transnational river basins. Processing techniques have been applied for the application of both image processing / GIS vector data techniques, along the image integration and creation of data fusion image products. Data have been classified using unsupervised neural network techniques. Automatic raster combination of the classification results with the vector GIS data have been applied for the final map updating.

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1. INTRODUCTION

Environment is put into constant stress through the various human activities and natural processes. In particular land and water systems are put into stresses in order to meet the demand of increased human needs. EC Water Framework Directive requires member states to monitor the environmental state of transnational river basins. Additionally, it demands common transnational agreements of water resources management of the river basins. However, problems may arise when the neighbouring countries are not members of the European Union, such as is the case of the river basins that are located in the Northern borders of Greece. Action must be taken to monitor water resources and if necessary to restore good ecological status of these water. A bilateral agreement between Greece and Bulgaria has been signed, concerning the distribution of Nestos waters. According to this agreement, 29% of the annual discharge is being disposed to Greece while the annual discharge is being assigned every five years. For the reasons mentioned above, a Greek-Bulgarian Experts Committee has the responsibility to determine, according to available measurements, the river annual water discharge. Data availability and easy access to all data are needed in order to support such policies.

Field measurements for monitoring the environment are expensive and difficult to conduct. Also, extending field collection programs to transnational river basins is currently still cost and prohibitive in many areas. The same applies to other environmental factors like the monitoring of land use change, industrial / mining activity, waste disposal sites etc. For example, only general geologic maps and low resolution topographic data are readily available for many of the transnational river basins of Greece. Furthermore these data are dispersed in various locations or organizations / Institutes involved in the monitoring of various parameters, while they are in different formats and this makes difficult, if not impossible, their integrated use.

Remote sensing technology has been used for several years in environmental studies. Although sensors such as Landsat TM were primarily designed for detecting land features, recent improvements now provide better spatial and spectral resolutions for aquatic studies than previously available (Zilioli, 2001, Dewider and Khedr, 2001; Stefouli, et al 2004). Additionally, various attempts are underway for developing Internet publishing facilities of GIS data (Karakos et al 2004, Alameh 2004, Zang 2003). Integrated use of GIS / Image processing techniques using one single low cost software package has not been evaluated as far as monitoring the land / water systems of a transnational river basin is concerned and this is included in the analysis. Much emphasis is given to extract information concerning a variety of parameters like land cover that influences (indirectly) water quality. To effectively implement remote sensing into a water resource management program, there still remain many unanswered questions and this is examined in the paper. GIS techniques are also used in processing multiple data that are of concern to a water management project. Finally in the framework of development of an integrated methodology for studying inland waters, using remote sensing and other data and techniques, it is also appropriate to give emphasis in analyzing the quality of water. Water quality is expressed by various physical and bio-geo-chemical parameters that describe complex and interdependent respective processes. Main objective of this study is the feasibility of the use of an integrated methodology, which includes remote sensing, and GIS techniques for appraising key parameters that are of interest to water resources management of transnational river basins.

2. DATA

2.1 Study area

Rhodope prefecture is part of the Thrace region, in Northern Greece. Nestos transnational river basin has been selected as a pilot project area. It is located in the Northern part of Greece (as shown in Figure 1). The study area is bounded between latitude 40° 51' 47.06'' N and longitude 24° 52' 49.15'' E N (Lower Right) to 42° 10' 48.6'' and 23° 17' 35.6'' E (Upper Left). Nestos river basin (6.178 square km) is the one of five transnational river basins that Greece shares with neighboring countries (the rest of them are: Axios river basin shared with FYROM, Aoos/Albania, Evros/Turkey, Strymon/Bulgaria). Nestos River springs originate from mountain Rila in Bulgaria, and flows SE into the Thrace sea.

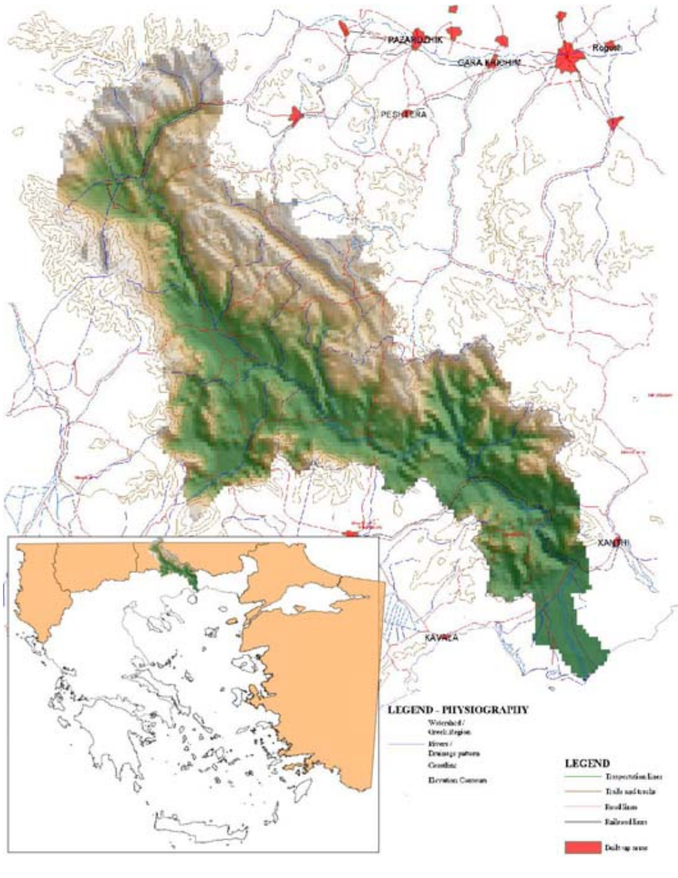

Figure 1. Overview of pilot project study area. Map output of the 1:1,000,000 scale Global Geodata.

The Rhodope mountains form natural boundaries between Greece and Bulgaria. The maximum elevation of the river basin is 1500 meters and the minimum 0 m. Nestos is a river of continuous flow and its length in the Greek territory reaches the 130 km (the total length is 234 km). It is one of the longest rivers in Greece with many branches, where a variety of geomorphologic units (rocky gorges, caves) is observed. Geologic formations consist of crystal-schists (known as Central Rhodope crystal-schistose unit).

The Greek Biotope/Wetland Center (EKBY), which has recorded all the rivers and lakes in Greece, marked the following biotic characteristics concerning the Nestos river basin:

Flora a) Hydrophytes (Nymphaea Alba, Lemna minor, Trapa natans) b) Riverside sylvan vert (Platanus Orientalis, Alnus glutinosa, Salix spp., Popoulus spp.). Along the riversides there are a lot of cultivated areas. Evergreen broadleaved vegetation (Quercus coccifera) also exists.

Fauna a) Pisces: Salmo trutta, Gobio gobio bulgaricus, Chondrostoma vardarensis, Barbus cyclolepis stroumicae, Orthrias brandti bureschi, Alburnoides bipunctatus strymonicus, Cobitis strumicae. b) Fowls: Phalacrocorax Pygmaeus, Ergetta alba Ciconia nigra Neophron percnopterus, Gyps fulvus Aquila pomarina, A.chrysaetos, Hietaaetus pennatus c) Mammals: Canis lupus Canis aureus Lutra lutra Capreolus capreolus.

Major usages include the following: Pasturing (3), Hydroelectric dams, Irrigation (2), Sand quarry (2), Recreation (1). (The numbers in parenthesis represent an upward scale of significance).

Possible sources of pollution of inland waters are fertilizers and pesticides, resulting from agricultural practices waste water which is rejected after poor treatment, into these waters, industrial waste that includes heavy metals, leaching from waste dump at mining sites or from geological formations and “imported” pollution. Decay causes of Nestos basin include the following: Manmade constructions (dams, etc), Over-pumping, Sand Quarry and Illegal Woodcutting. Four hydroelectric dams, are constructed by the Public Power Corporation (P.P.C) in the sites of Thesaurus, Toxotes, Platanovrissi and Temenos.

The Delta area of the river basin is under special protection (European Directive 79/409/EEU & Barcelona Contract, Region of international importance according RAMSAR convention). In this area, which is characterized as chase harbor, drilling, woodcutting & landfill are prohibited. Shallow lagoons and narrow sand dunes are formed as a result of marine streams and action of wind. The elevation is 0 meters, it covers an area of 120000 square meters and its coordinates are φ=24,7857° , λ= 40,914°. Major usages are: Irrigation (3), Aquiculture (3), Pasturing (3), Wood-cutting (3), Tourism (2), Piscary (1) and Recreation (1).

Decay causes are: Drainage (3), Hydraulic and other Constructions (3), New Built-up areas or expanding of the preexisting (3), Industries (3), Tourist settlements (3), Agriculture (3), Illegal woodcutting and Chase (3), Landfill (1).

Main pollution sources include: Solid and liquid wastes of built-up areas and industries, “imported” pollution, agriculture activity.

2.2 Data and method of analysis

The aim of the work has been to evaluate the applicability of the use of digital satellite imagery (Landsat 7 images), along with available topographic, geologic, hydrologic and environmental data for the mapping and monitoring purposes of Nestos river basin. Emphasis

is given on the selecting variable data that are of interest in aspects of hydrologic management of transnational river basins.
One Landsat- 7 Enhanced Thematic Mapper Plus (ETM+) scene of Path 182 & Row 032, has been used in the analysis with acquisition time 20/8/2001. Synergistic use of, (1) topographic maps at 1: 1,000,000 (Global Reference Geodata, 2003) & 1:250,000 scales of the Hellenic Geographic Service published at 1970, (2) geologic map at 1: 400,000 scale (Archives of Ministry of Public Works' 1947), (3) meteorological and hydrologic / water quality data have been used in the analysis. Selected data of the Global Reference Geodata are shown on the map of Figure 1.

Existing field observations of water quality parameters were obtained for the Nestos river, from the sampling Programs of the Ministry of Agriculture (www.minagric.gr). Three gauges for monitoring waters quality are installed by the Ministry of Agriculture in Nestos river basin as shown in Figure 2 (Toxotes, Papades Bridge, Delta). Gauges' monitoring systems record the air and water temperature, electrical conductivity and water discharge, while samples of the Nestos waters are being tested in order to estimate quality parameters as: PH, Sodium, Magnesium, Calcium, Total Phosphorus, Cadmium, Sodium Absorption Rate (S.A.R), Sodicity, Nitrates, Nitrites, Chlorine, Dissolved Oxygen, Organic Carbon, Sulfurous, Repletion, Acid Carbonate, Water hardness (Permanent & Impermanent). All the time series of the values, measured or evaluated by laboratory tests, up to 2001, have been written down in sheet forms.
Four hydro-meteorological gauges have been installed by the General Secretariat of Public Works, in the Nestos river basin for the monitoring of precipitation in the area. The sites of the gauges (Toxotes, Skaloti, Paranesti & Mikroklisoura) are shown on Figure 2.

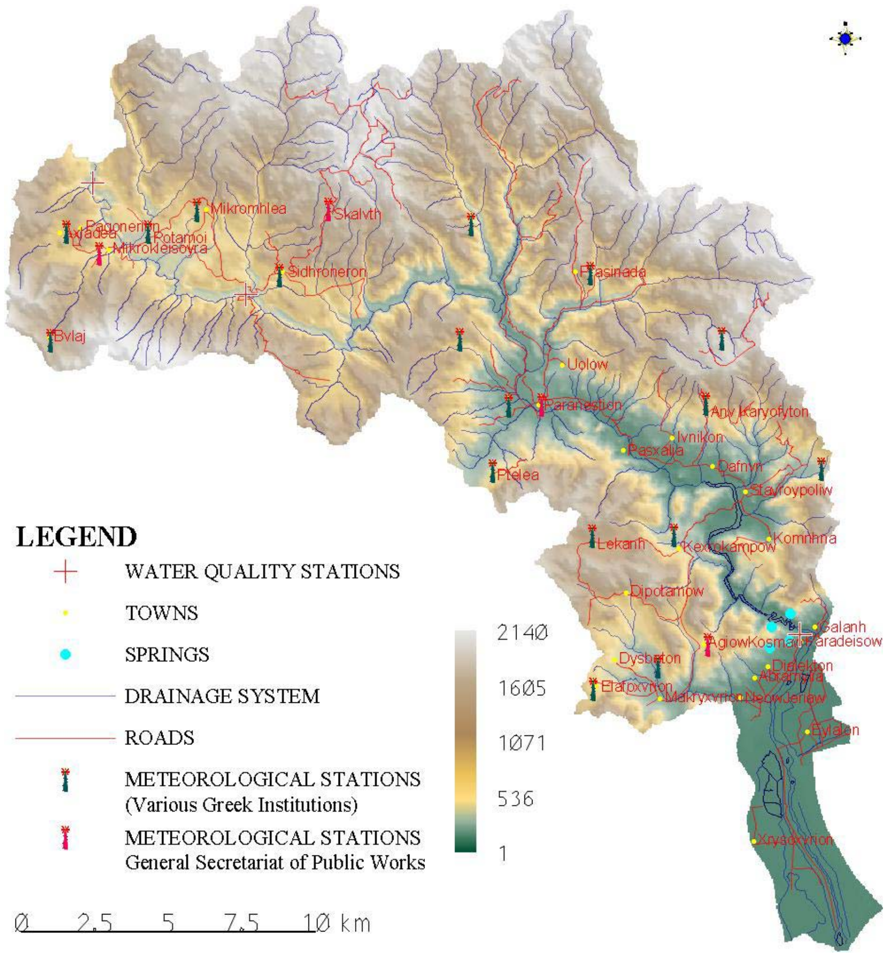

Figure 2. Map of 1:250,000 scale of the Greek part of the Nestos river basin

All map data have been converted into digital form. The old topographic map of the 1947 edition was used in order to compare the possible changes of the relief, that can be attached either to errors of the senior survey and mapping or to natural erosion procedures. The old geology map (1947) is shown, after being digitized, in figure 3.

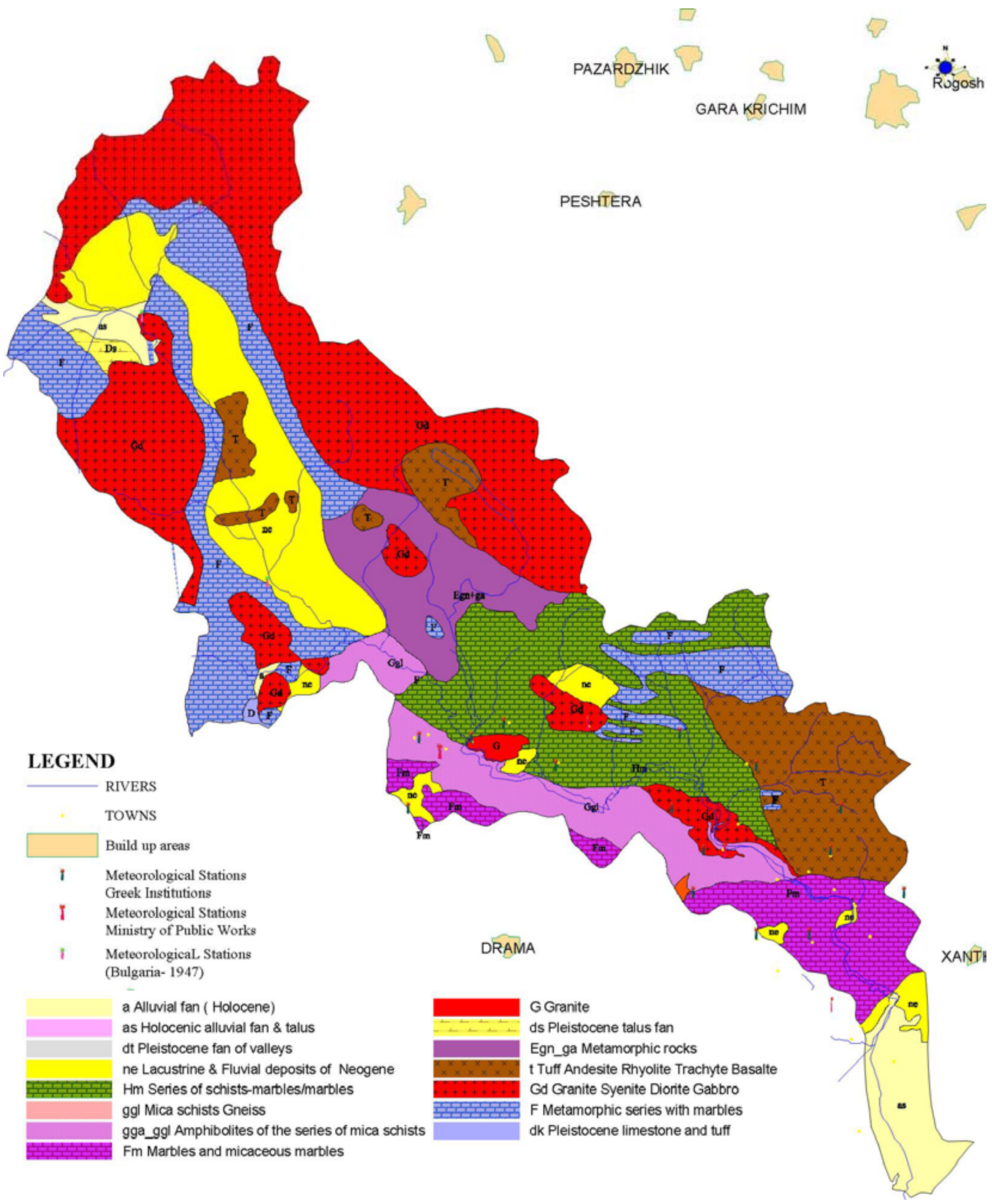

Figure 3. Nestos River: Map of Watershed (1947)

The hydrologic, meteorologic and land use data, as well as field measurements concerning water quality characteristics have been also stored in the GIS system so as to facilitate any water quality analysis. In the final map, the sites of the existing meteorologic / hydrologic and river discharge gauges are marked.

Processing techniques that have been applied include integrated image processing / GIS vector data techniques. Combination of different resolution data using data fusion techniques proved to be effective as far as the land cover and the interpretation of geologic features are concerned because complementary information for the same target is combined. Neural network algorithms are quite effective for the satellite data classification (Vassilas N. and Charou E. 1999) and of the data fusion results. The Kohonen's self-organizing map (SOM) (Kohonen 1989) has been used for clustering and vector quantization. SOM was used for the classification for the satellite images. The area extent of “water surfaces” has been mapped accurately in all cases.

3. ANALYSIS OF REMOTE SENSING DATA

Land cover may influence water quality parameters of the river basin. Also geologic features influence the flow parameters of surface / ground waters. Remotely sensed data have been used in mapping land cover patterns and geologic features, Figures 4 and 5.

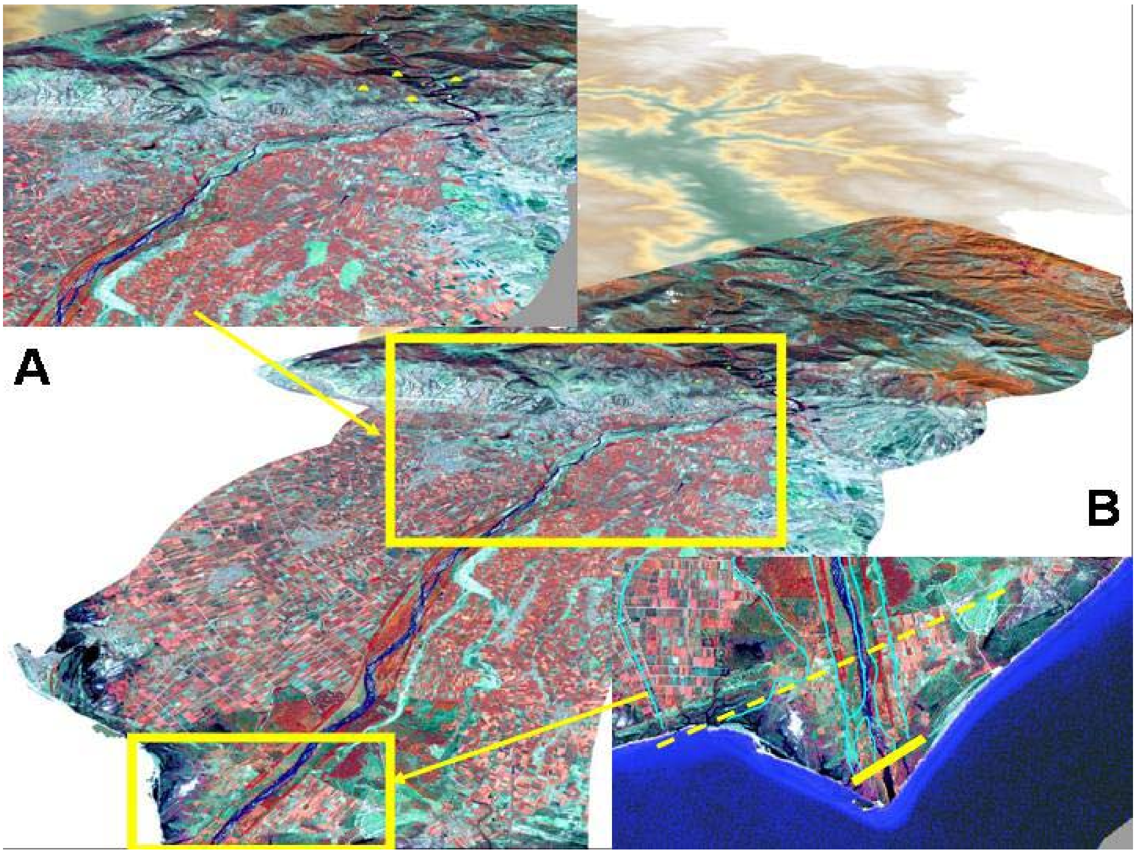

Figure 4. Overview of the satellite image covering the outflow area of Nestos river that it is displayed with the R:G:B:I / 4:5:3:P color band combination (Data fusion result of the 30 m multi spectral bands with the 15 m Panchromatic image - P). **A.** Detail of the northern part of the image. Yellow dots show the location of karstic springs. Various features of interest can be interpreted: boundaries of geological formations and tectonic lines (faulting) along with land cover types (vegetation patterns with the bright orange red colors, cultivated / irrigated fields with the pink color, water surfaces with the blue color, residential areas with the grey color, bare land with the grey light blue colors). **B**. Detail of the Delta of Nestos river: Extension of coastline to the sea (1.12 km^2) for the last 30 years is indicated (solid yellow line) after overlaying the map data of the 1970 edition. Anticipated old coastlines can be also interpreted (yellow dash line).

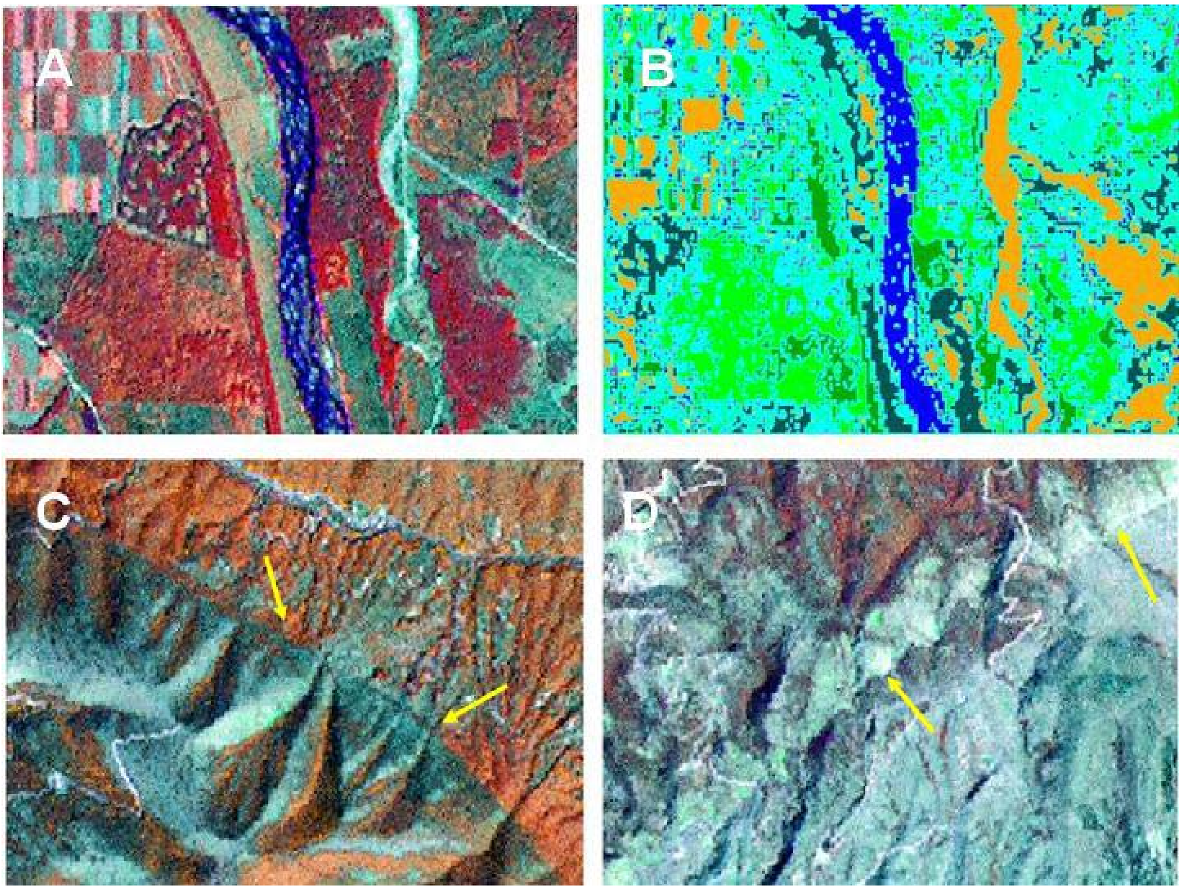

Figure 5 A to D: Sub-areas extracted from the satellite image of Figure 4.
A. Detail of area of the Delta of Nestos river. Vegetation patterns and water surfaces along with cultivated areas can be distinguished.
B. Result of the classification process. Land cover types (i.e. water surfaces – blue color, vegetation – green colors, bare land – orange color) can be mapped accurately.
C. Image detail of the lithologic boundary / tectonic contact between the basic formations and marbles (yellow arrows).
D. Boundary between Neogene formations and marbles (yellow arrows). Hydrogeologic maps can be updated with the interpreted features.

Accurate information and uniform data of the total area of the Nestos river basin can be obtained. Land cover patterns and geologic features can be mapped to scales up to 1:50,000. Therefore remotely sensed data can be effectively used for map updating procedures. Remotely sensed data can contribute to a river basin water resource assessment project through its ability to show spatial patterns of land cover. Also the multi-temporal nature of the data gives the opportunity to compare the status of land cover / surface waters in different dates. All images (R:G:B:I color schemes) along with the interpreted information and classification results are delivered to the informational Atlas and therefore end-users can view the high resolution enhanced imagery and also use them as a reference for mapping and interpreting features of interest.

4. WATER QUANTITY / QUALITY

Watershed analysis has been included while the following parameters have been derived: 1. Watershed area, 2. pour points between neighboring watersheds 3. flow paths and 4. Sub-basins. Varied attribute information is also created and saved with the flow paths and watersheds. The information created by these area-wide computations can be used as input for further analysis of water resource issues, flood and erosion hazard, and movement of pollutants. The Global Reference Geodata have be used to derive the overall watershed area and flow paths / basins of Nestos river and these have been compared with existing map data. As shown in Figure 6 the output results related well with the existing map data of similar scales. The 1:400,000 scale Map of the Nestos Watershed (1947) shows a surface extend of 5648 km^2, while the estimated one is of the order of 6454 km^2. Difference is partly attributed because the sub-basin A (Figure 6) is considered as part of Nestos river basin and this is due to the low resolution of DEM. Estimated flow paths relate well the stream network depicted on topographic maps of the area. Stream order is classified according to Strahler (Horton, Shreve & Scheidegger) system and this can be used for estimating morphologic parameters of the basin. This information is readily available as GIS data base information to end-users through the Atlas informational system.

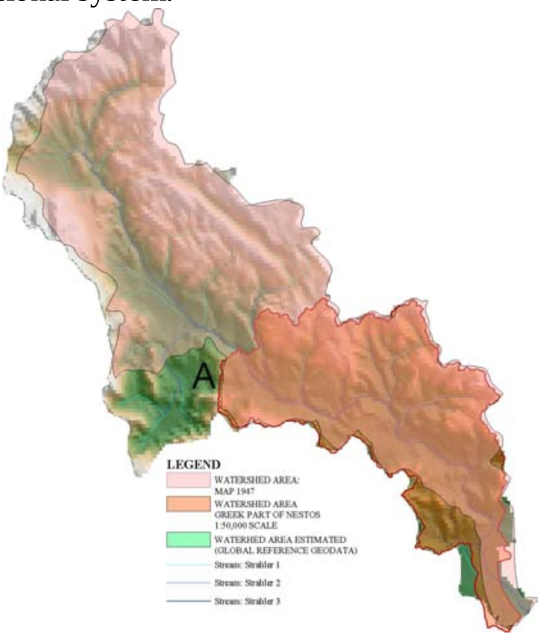

Figure 6. Comparison of estimated by the use of the DEM of Global Reference Geodata watershed area of Nestos river with those derived from the existing maps.

Rainfall data show a fluctuation but the annual average over the last 40 years period is more or less constant. Linear regression shows a decline of precipitation that it is less than 20% for the last four decades. Therefore it is concluded that natural factors determining surface water of the river play a minor role compared to human activities that are taking place in the area. This is attributed to abstraction of water for Hydropower generation, but during the last decades it is due mainly to increased pumping of ground water used for irrigation purposes. A decrease of freshwater inflow is already obvious in the delta, due to irrigation dam construction and increasing irrigation projects and water drilling in the upstream area of the

River Nestos. Similarly, the groundwater level has shown decreasing trends, resulting in the restriction of marshland (Argiropoulos 1996).

The following histograms are based on the records of the National Bank of Hydrologic and Meteorological Information (NBHMI/Ministry of Environment, Physical Planning and Public Works).

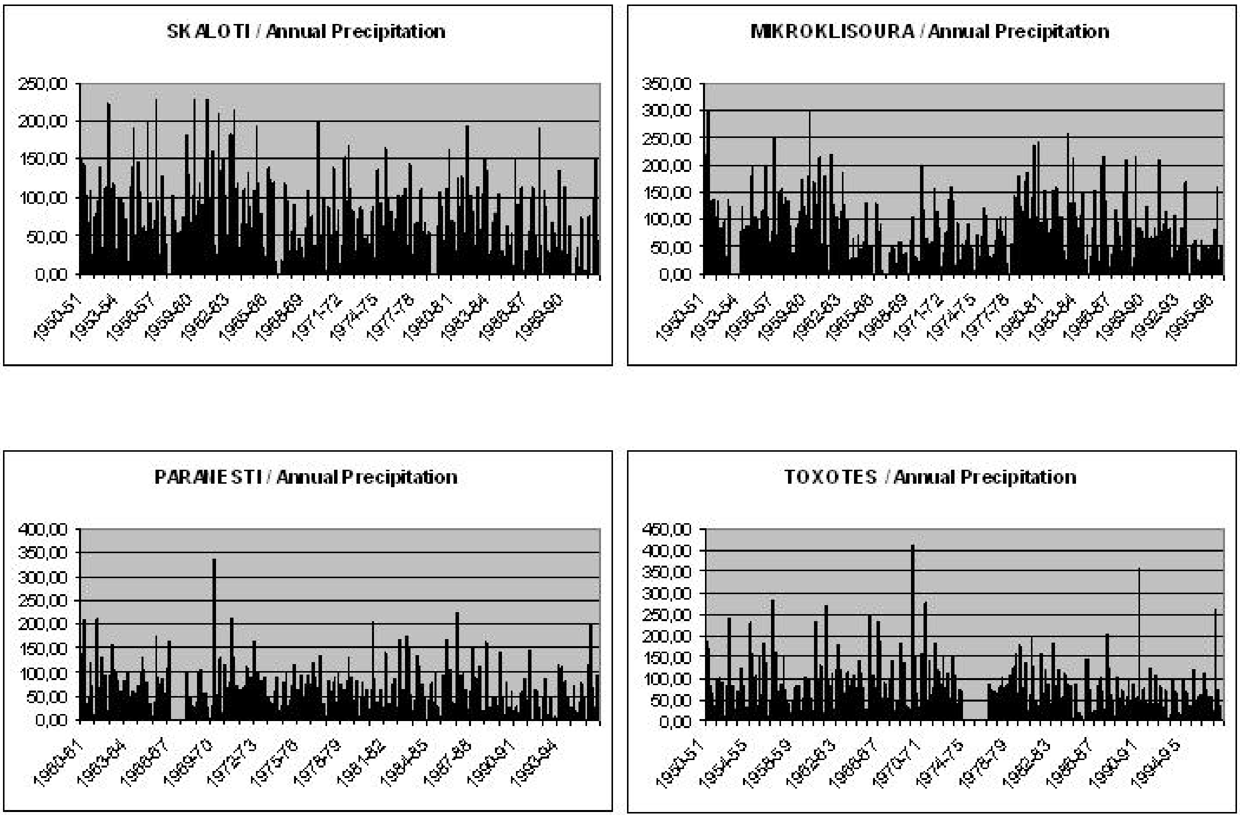

Figure 7. Annual rainfall measured in four hydrologic gauges.

Three gauges are installed by the Greek Ministry of Agriculture in the Nestos river basin in order to provide constant field measurements of water quality parameters. The histograms below concern only two of the quality parameters and were selected by the criteria of the time series' completeness. In general, no seasonal differences have been observed to exist in relation to water quality.

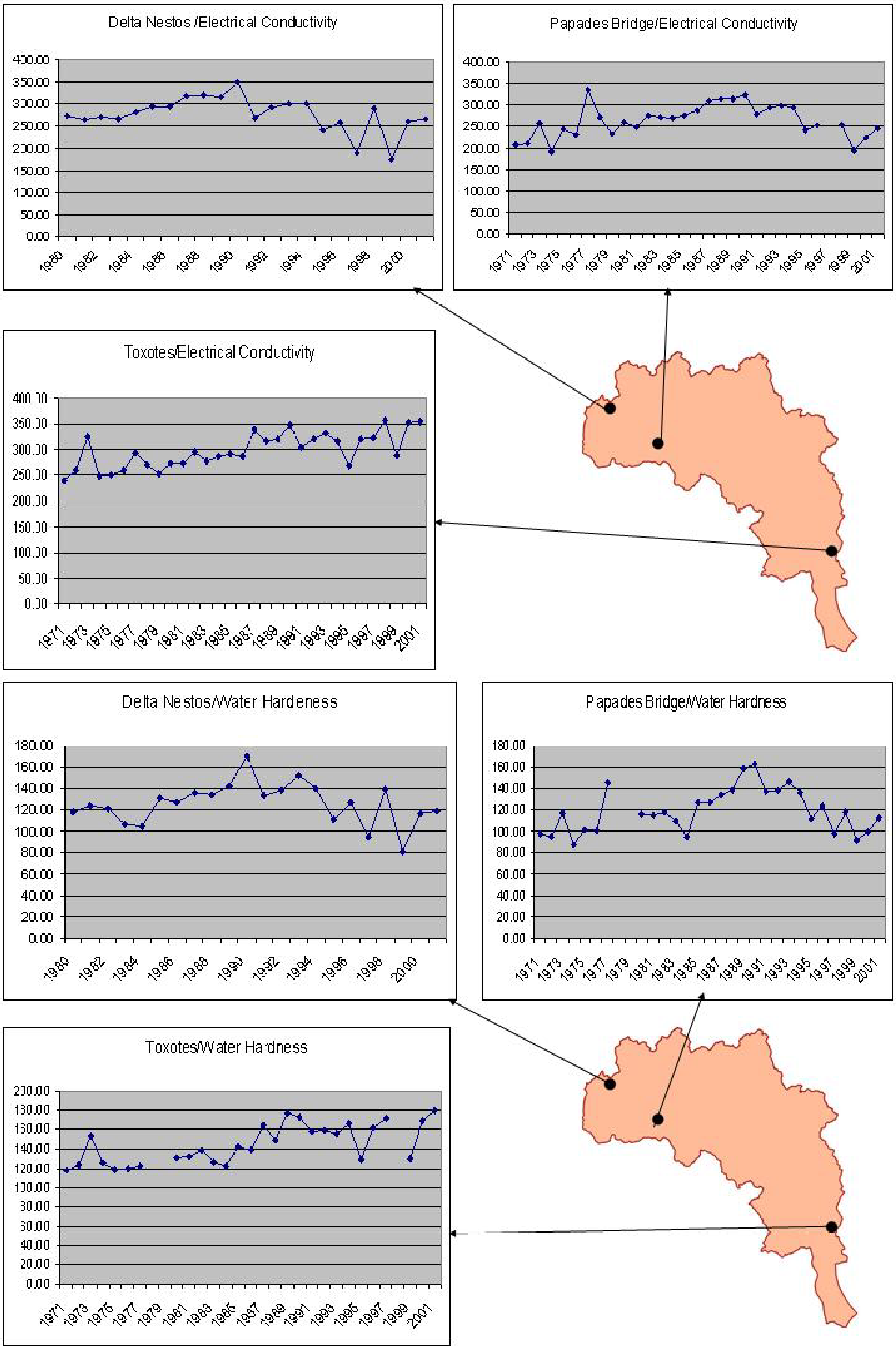

Figure 8 a & b. Variation of quality parameters in three different sites.

One of the forthcoming scopes is to update the data base with the most recent data of precipitation and water quality, the river discharges measurements, and the data from various studies carried out in the area of interest. These refer to the Greek part of the Nestos river basin that covers nearly 40% of its total area. Furthermore, on the basis of a transnational agreement, in order to achieve the target of Integrated Water Resources Management, the data base has to include similar data concerning the Bulgarian part of Nestos river.

5. DISSEMINATION OF INFORMATION

The project has resulted in multiple data that could be useful to different authorities that are responsible for the water resources management of the area. All data have been organized in a form of an informational Atlas which can then be distributed in the form of a CD or on the WEB using the TNT software products. TNTatlas software is a free product for viewing hierarchical atlases prepared in TNTmips (www.microimages.com) with HyperIndex Linker or for single layout atlases. Different layouts have been organized for the total area of the Nestos river basin (Figurs 1-6). With the use of TNTatlas, all data can be distributed on a CD and take advantage of its low media cost, small physical size, permanence of media, and quick access to large collections of geospatial data for the involved parties in the management of the project area. With TNTatlas, even computer users who have little training can easily access the organized geospatial information concerning the study area. And finally all data can be used in any kind of computer the end-users are using. The objects and views in the electronic atlas can be complex. The stack of spatial information can display multiple objects:

- side-by-side (before and after views),
- overlaying objects (vector and CAD lines over raster images),
- graphical symbol overlays (such as icons or pie diagrams), or
- additional reference information (like map grids, text blocks, and legends).

The TNTatlas navigator window lets the user click arrow buttons to move to related materials that continue "off the edge" of the current view. A tool menu lets the user make simple on-screen measurements with calipers, protractor, or planimeter and annotations.
The atlas materials can be hosted on an intranet or Internet site with the TNTserver software. Visitors of the site can select the atlas, and then their browser automatically downloads the free TNTclient Java applet. All of the functionality of the free TNTatlas software is provided in TNTclient.

6. DISCUSSION OF THE RESULT - CONCLUSIONS

Remote sensing provides valuable information concerning different hydrological parameters of interest to a transnational river basin assessment project. Monitoring is supported due to the multi-temporal character of the data. For over all developments of a region reliable estimate of water quality and quantity of rivers is of paramount importance. Land cover patterns and geologic features are mapped on the satellite images. Water quality assessments can also be performed. Additionally, satellite data can be analyzed to generate GIS database information required for hydrological studies and the application of models. Generated database can be used to assess changes that are taking place in the river basin and its surrounding environment. The added advantage of the proposed approach is that it makes available to end-users a variety of the data and that it helps in efficient analysis and prediction. An advantage of using remote sensing is that data for large areas within a single image can be collected quickly and relatively inexpensively, while this can be repeated through selected time intervals. In addition, satellite techniques are very capable of supplementing the comparison experiments by providing additional geographic information about the setting. The combination of data from different sources linked by the powerful prospects of new Earth Observation techniques will result in the development of new knowledge that can be used for supporting policies like the EU 2000/60 Water Framework Directive. It is indicated that satellite / GIS techniques can be used for spatiotemporal monitoring purposes of river basins.

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