WEB-BASED INFORMATION SYSTEM FOR POLLUTION MONITORING OF LAKE OHRID

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Abstract. In this paper, we present a Web-based information system for pollution monitoring and analysis of Lake Ohrid. Our work is related to the ecological state of Lake Ohrid, which represents a rare natural ecosystem inhabited by many endemic and relict species. Aim of the study is to present the possibilities offered by the Web application, such as fast information access, support of distributed collaboration by information sharing instead of exchange, acquisition and analysis of pollutant data, database processing based on lake models, as well as GIS analysis. In this way, the data and the analysis are performed in one place and they are available to any user having only a Web browser.

Keywords: ecological modeling, fuzzy logic, Lake Ohrid, pollution monitoring, water resource management, Web-based information system

1. Introduction

The Institute for Computer Science and Informatics at the Faculty of Electrical Engineering of "St. Cyril and Methodius" University in Skopje, in cooperation with the Hydrobiological Institute from Ohrid, has been working since 1996 on ecological state of water resources. The long-term objectives of our research activities were:

– On the basis of previous research results, to provide an analysis of different parameters for estimation of the eutrophication status of the Lake Ohrid.
– To develop a complete mathematical model with all relevant processes in the lake.
– To apply fuzzy logic for eutrophication analysis and estimation of trophic state of the lake.
– To provide multimedia 3-D GIS modeling and analysis of the Lake Ohrid ecosystem.
– To put all measured and calculated data on a website providing an advanced decision support information-monitoring system.

An ecological model for Lake Ohrid that estimates the level of eutrophication in the Lake Ohrid and shows general trends of the lake behavior has been presented in

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Davcev *et al.* (1996) and Mitreski *et al.* (1998). The specific nature of the lake has been taken into consideration and embodied in the model. Such dynamic model, which tends to predict future eutrophication and trophic state lake-wide, is the first attempt undertaken in describing the ecological state of Lake Ohrid.

Fuzzy logic is applied in order to obtain a long-term evidence of the current and future status of the Lake (Koneski *et al.*, 2001). Fuzzy rule-based models have some advantages over classical models because:

i. they use less parameters,
ii. they are less sensitive to parameter change, and
iii. they are less complicated.

A concept and some preliminary design for a Web application for handling the data for Pollution Monitoring System (PMS) have been presented in another study (Mitreski *et al.*, 2000). Several modules have been introduced: data acquisition module, data storage module (supported by relational DBMS), data processing and analysis module (including a 3-D analysis) and Web-based data presentation module.

In this paper, we present an integrated Web-based information system for the Lake Ohrid that gives the possibilities offered by the Web application, such as fast information access, support of distributed collaboration by information sharing instead of exchange, acquisition and analysis of pollutant data, database processing based on lake models as well as GIS analyses. In this way, the data and the analysis are performed in one place and they are available to any user having only a Web browser.

The paper is organized as follows. Section 2 gives the related work, while Section 3 presents the Web-based information system architecture for the Lake Ohrid. In Section 4, the design and implementation of Web-based information system for the Lake Ohrid is presented, while Section 5 concludes the paper.

2. Related Work

Our system was developed in accordance with the recommendations similar to those given in (Border Institute, 2003). For example, we introduced a Geographic Information System (GIS) to provide different data necessary for precise geographic locations, emergency readiness, health data, socio-economic and other information relevant to the Lake environment. Our Web-based communication system will include binational (Former Yugoslavia Republic of Macedonia-Albania) content. We have developed an interactive calendar to promote key events and activities and provided a support for ecological education and training activities (see the reference, Open and Distance Learning Center). In addition, we provided a support for short-term and long-term prediction analysis and protection of the Lake eco system.

In a study (Panagaea information Technology, 2002) of more than 150p., many alternatives have been identified for addressing the needs for geospatial data storage, maintenance, access and distribution. The alternatives were evaluated according to the possibility of spatial data viewing on-screen through a Web-mapping viewer. It was concluded that systems implemented using different technologies hinder the interoperability required in providing cohesive data viewing and mapping. In the second part of the study, many alternatives and options for the management of spatial documents have been introduced and evaluated. Although, some stand-alone system were mentioned as well, the advantage and superiority of Web-based systems was emphasized. An additional functionality to the basic establishment of a shared environment from which data and information resources can be utilized was proposed and elaborated in the study. It is based on Web Mapping Services (WMS) and Web Feature Services (WFS). Our system is in accordance with the given recommendations.

In Molkenthin *et al.* (2002), the concept, implementation and application of the Web-based hydroinformatics system 'Turtle' are described. The measurement data from the Lake Constance in Central Europe served as a basis for validation of the simulation program. The basic idea for information modeling of measurement data is the application of object-oriented modeling by using JAVA. The system support stand-alone application, thin client mode and fat client mode to support the use via Internet. Three modules of the system are emphasized: on-line monitoring module, pre-analysis and information mining module and long-term reporting and archiving of the measurement results. It is not clear what type of data mining is performed and how the data are organized in the archives. Although this system offers some similar functionality as our system (like fast information access, support of distributed collaboration by information sharing instead of exchange etc.), it does not offers a prediction analysis based on the mathematical model of the Lake. It is strongly oriented towards monitoring based on measurement data, while our system provides a deep analysis of the state of the Lake based on several models, including the fuzzy model as an attempt to express the uncertainty.

In Lijian *et al.* (2002), a Web-based environmental data management system for air pollutant data monitoring, presentation and analysis is presented. It is also based on the object-oriented design and programming. Although some similarities exist on the system level with our system, this system is air quality data acquisition and monitoring system specifically developed for air pollutant data. An air quality forecast model is under development.

In Umgeni Water (2001), within the River Health Programme, some Web-based monitoring system have been developed as well. One of them is a South African Scoring System (SASS), which allows a broad network of 'monitors' around the country to monitor their own ecosystems. The water quality is classified according to the Water Quality Index and SASS biotic index. However, there is no information about the architecture of the system as well as the efficiency of the water quality improvement by 'catchment management.'

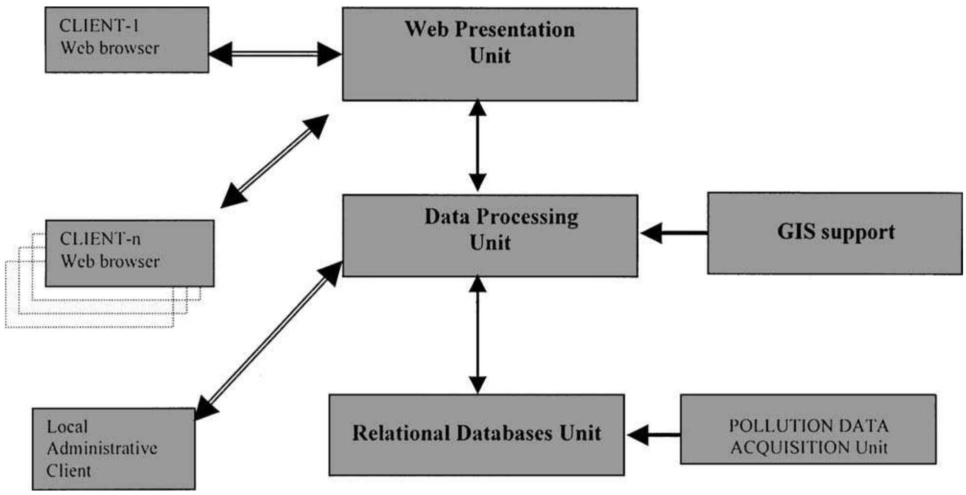

Figure 1. Web-based information system architecture.

There are many monitoring solutions for coastal waters, rivers and lakes. These systems are modular and consist: data acquisition, telemetry, data storage and presentation etc., as in Sturm *et al.* (1998). However, we could't find an integrated Web-based information system based on similar mathematical models or with similar characteristics and possibilities.

3. The Web-Based Information System Architecture

Web-based information system architecture for the Lake Ohrid is shown in Figure 1. It is basically three tier architecture that consists of presentation tier, middleware tier (data processing tier) and relational database tier. In addition, the integral part of the system is the data acquisition unit, as well as a GIS support for analysis and presentation purposes.

The system supports 'fat' client mode (Visual Basic application in our case) and 'thin' client mode to support the use via Internet. Visual Basic application is used by local administrative users of the system and has a direct access to the databases. The other users use the system via Web by using only the browser.

4. The Design and Implementation of Web-Based Information System

The Web-based information system is hosted on http://odl-skopje.etf.ukim.edu.mk/ecomodel/. It is based on the ecological model of the Lake Ohrid as well as the Web-based pollution system. The fuzzy approach, as a tool for environmental modeling is used for long-term prediction.

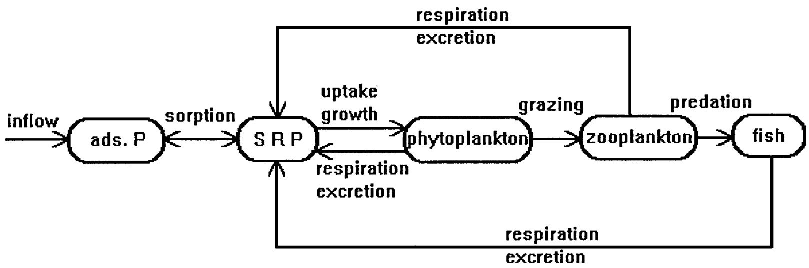

Figure 2. Conceptual diagram showing the components of the model of the phosphorus cycle.

4.1. ECOLOGICAL MODEL OF LAKE OHRID

In this part of the Web-based information system, information about the ecological model of the Lake Ohrid is presented. A conceptual/functional diagram which is a basis for the mathematical model is presented in Figure 2.

The conceptual diagram illustrates the flow of phosphorus through the food web. Because the phytoplankton growth in the lake is only phosphorus limited, other nutrients are not considered. The model takes into account only the water column (sediment layer has not been considered in this research).

Our work is related to the ecological state of Lake Ohrid, which represents rare natural ecosystem inhabited by many endemic and relict species. The lake faces accelerated deterioration of its waters and a change of the trophic state of this aquatic ecosystem, mainly caused by nutrient load. 'Man-made' eutrophication, in the absence of control measures, proceeds much faster than the natural phenomenon and is the major reason for pollution of this lake.

We proposed a mathematical model that gives general picture of the level of eutrophication in the Lake Ohrid and shows general trends of the lake behavior. Our model has been inspired by some other ecological models, and by the analyses conducted on Lake Ohrid. The specific nature of the lake has been taken into consideration and embodied in the model. The nutrient cycling in the sediment is not included. Such dynamic model, which tends to predict future eutrophication and the trophic state lake-wide, is the first attempt undertaken in describing the ecological state of Lake Ohrid.

On the basis of the biological and chemical processes in the lake, the mathematical model is comprised out of three equations describing the behavior of the available phosphorus, phytoplankton and zooplankton.

Available phosphorus is described mathematically as the sum of the decomposition and the algae respiration processes, minus primary production, which are highly phosphorus dependent.

The phytoplankton dynamics is described as the primary production of the specified plankton decreased by the processes of algae respiration and zooplankton consumption.

Zooplankton dynamics is described mathematically as the zooplankton consumption process decreased by the zooplankton respiration. More details can be found in Mitreski *et al.* (1998).

4.2. Web-Based Pollution System

The structure of the pollution monitoring system (PMS) includes three levels (as described in Section 3):

– *Data acquisition level* responsible for systematization, validation, comparison of data with alarm limits and creation of dynamic part of the relational database system; the static part of the database contains information about standards, limits, models etc.
– *Data handling level* responsible for supervisory control and specialized data analyses and model evaluations; it's also responsible for integration of on-line with off-line information to make statistical reports and data presentation.
– *Management level*, which is responsible for short-term decision and long-term strategies for the pollution reduction approach.

Our PMS consists of six measurement points along the coast of Lake Ohrid and four measurement points along the rivers. PMS was used for measurement of the following parameters: temperature, pH, total phosphorus, dissolved oxygen, total alkalinity etc.

For example, temperature measurements were made by Pt100 sensor; pH measurements were made by *HI 1910B* sensor for calm water and with EURO2015 sensor for rivers. Measurement sensors are connected with intelligent microprocessor system PH500122 in local stations. The data are measured on-line by the instruments and transmitted to the central station where they are processed by the computer system.

The measured values are organized as relational database, which is suitable for statistical analysis using different OLAP (on-line analytical processing) tools. One example of graphical presentation of pH measurements is given in Figure 3.

Aquatic ecosystems are extremely complex and the basic objective of most PMS is to determine the status of the ecosystem. Mathematical models are built and validated with empirical data from our PMS. Web-based pollution monitoring system will give more possibility for predictive models about Lake Ohrid in the future.

Using PMS, the user is able to specify the location on the Lake (by selecting a location on the map) and the time period for the graphical presentation of measured data as shown in Figure 4. The application will generate dynamically the graphical presentation from the database for all measured parameters as shown in Figure 5. One of the main objectives of the PMS is to provide a real time on-line monitoring and efficient protection of the environment.

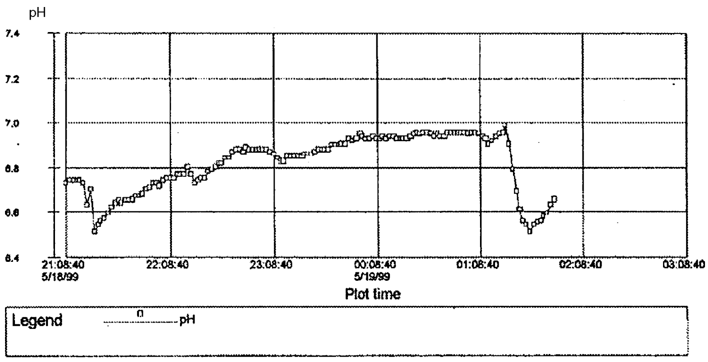

Figure 3. Graphical presentation for the pH measurements.

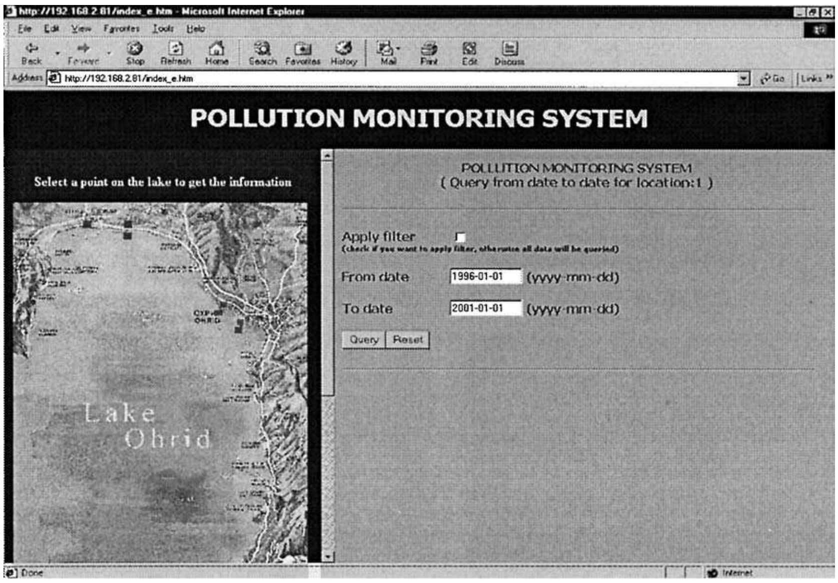

Figure 4. Query for the selected location (in a selected time period).

The Web-based PMS is implemented using Red-Hat Linux and SQL RDBMS. PHP Graph module dynamically creates graphical presentation from DBMS for all available parameters. PHP3 Web generator dynamically reads measured data and using HTML orders, Web browser will display all presentations to the client.

In addition to the previous PMS possibilities, by using our GIS support unit it is possible to provide 2-D visual model of the phosphorus pollution in the littoral zone (see Figure 6), as well as 3-D visual models for the phosphorus and temperature in the pelagic zone on different depth levels (see Figure 7). More details about this 2-D and 3-D analyses can be found in Mitreski *et al.* (2003).

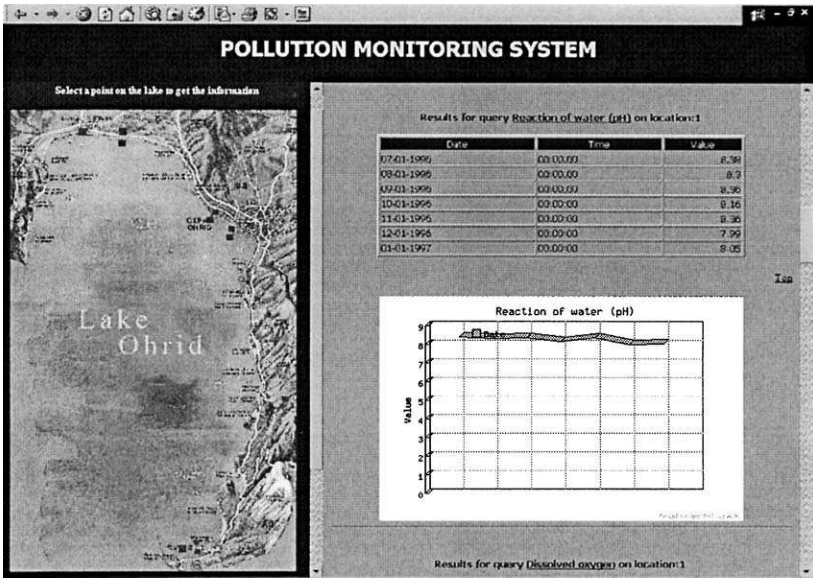

Figure 5. Graphical presentation for the selected location (in selected time period) – for all measured parameters.

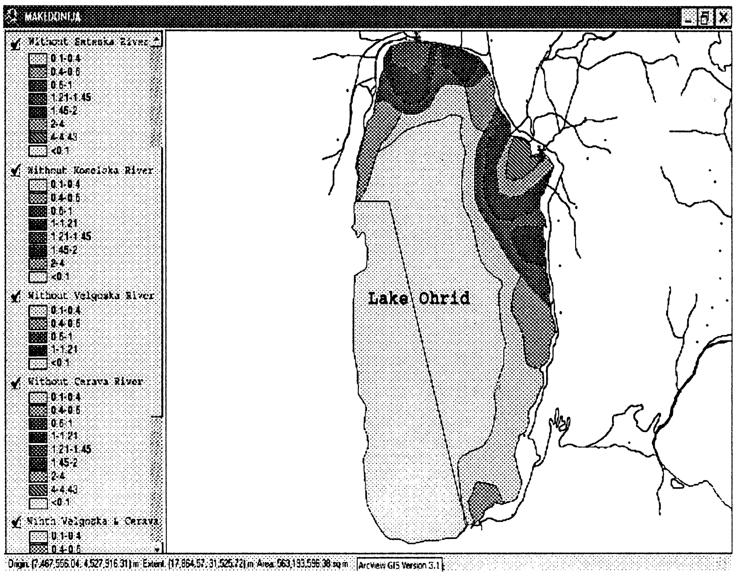

Figure 6. 2-D visualization of the phosphorus pollution in the littoral zone.

4.3. FUZZY APPROACH

Fuzzy logic is applied in order to obtain more realistic picture about the status of the lake and its prediction. An important feature of fuzzy sets is that they provide

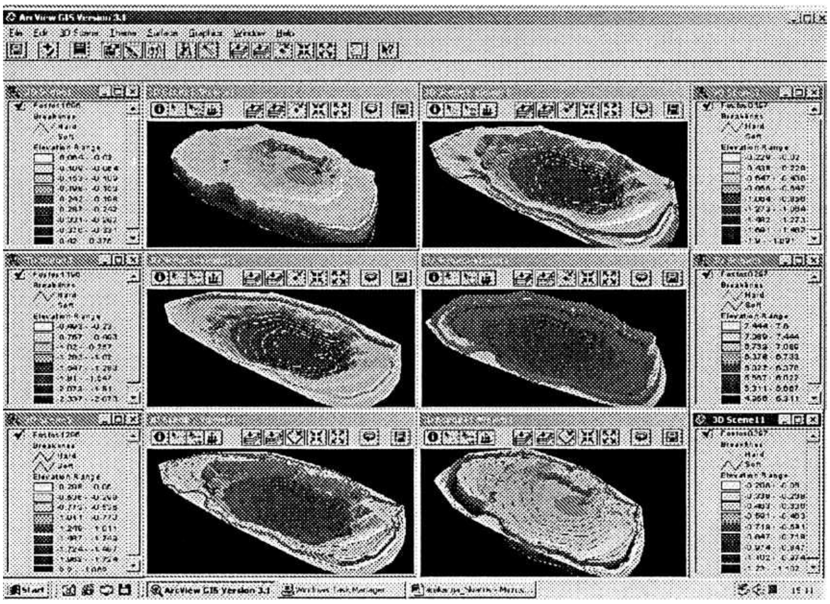

Figure 7. 3-D virtual model for phosphorus for the period of six months.

formalism for incorporating ambiguity and lack of quantitative data in a classification scheme. A model for lake trophic state forecast is developed, based on a fuzzy expert system using a rule-based scheme. A fuzzy inference procedure is used to evaluate the rules governing the lake system and to produce a trophic state index. Because fuzzy theory deals with membership functions, they are defined for the input and output variables. The vaguely defined membership functions must not be judged as weak parts of the model, but more as a best attempt to express uncertainty. Although it is often not feasible to define the membership function that adequately captures a given linguistic term, an exemplification procedure can use questions of the form: What is the degree of membership of x in A? or What is the degree of compatibility of x with L_a?, where L_a is the linguistic term that we want to represent in a given context by fuzzy set A. These questions, regardless of their form, result in a set of pairs $\langle x, \mu(x) \rangle$. The set is then used for constructing the membership function of a given shape (triangular, trapezoidal, S-shaped, bell-shaped, etc.). Having defined membership functions for the input and output variables, a fuzzy expert system can be consulted. This is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic, to reason about data. The rules in a fuzzy expert system are usually of a form of IF-THEN rules. The rule's premise describes to what degree the rule applies, while the rule's conclusion assigns a membership function to each of one or more output variables. Most tools for working with fuzzy expert systems allow more than one conclusion per rule.

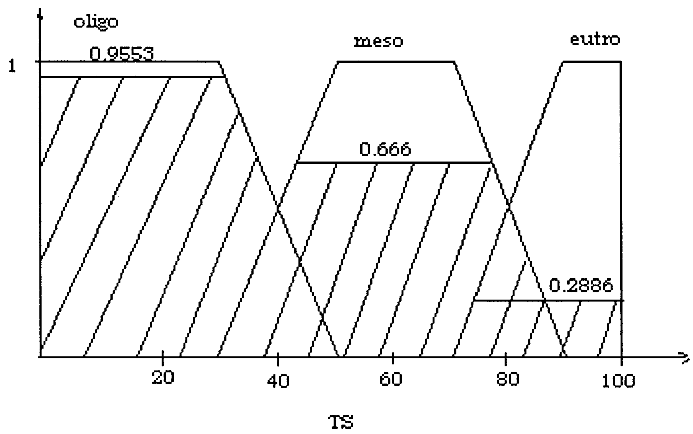

Figure 8. The output fuzzy set representing the trophic state.

Under inference, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Under composition, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Finally the defuzzification (optional) process is performed, which is used when it is useful to convert the fuzzy output set to a crisp number.

Three main parameters observed in this study are the total phosphorus concentration in the lake (measured in mg/L), the concentration of the chlorophyll a (mg/m^2), and Secchi disk transparency of the lake (measured in meters). These are the three input parameters in the system, which on its output has the trophic state, as an important sign of the ecological state of the lake. After applying the inference process for the three input parameters, a single output fuzzy set is obtained for the trophic state of the lake, and the graphical representation is shown in Figure 8.

We can see from Figure 8 that the state of the lake is oligitrophic. More details about our fuzzy model can be found in Koneski *et al.* (2001).

5. Conclusion

In the paper, we present the features of the Web-based information system for pollution monitoring of Lake Ohrid, hosted on http://odl-skopje.etf.ukim.edu.mk/ecomodel/. The main contribution of this system is to provide a fast information access, support of distributed collaboration by information sharing instead of exchange, acquisition and analysis of pollutant data, database processing based on Lake Models as well as GIS analysis. The Web application offers information suitable for public purposes and to relevant decision-makers coming from the academic world, governmental sector and the industry. We plan in our future work to provide wireless and mobile connection between the measurement and monitoring stations on the lake and the Web-based information system. The wireless and mobile access to the Web-based information system will be possible for all users as well.

References

Border Institute V: April 28–30, 2003, http://www.scerp.org/bi/BIV/moya.pdf.

Davcev, D., Mitreski, K., Boskovska, V., Koneski, Z. and Andreevski, C.: 1996, 'Water quality assessment in coastal environment by multimedia computing', in *Proceedings of the First International Conference on Environmental Problems in Coastal Regions Coastal Environment '96*, Rio de Janeiro, 1996, pp. 33–40.

Koneski, Z., Davcev, D. and Mitreski, K.: 2001, 'Fuzzy modeling of the trophic state of lakes', in *Proceedings of the IASTED International Conference Artificial Intelligence and Application*, Marbella, 2001, pp. 287–291.

Sun, L., Lei, S., Chen, Y., Hsieh, H.-T. and Pepper, D.: 2002, 'Environmental data management system – From data monitoring, acquisition, presentation to analysis', *Computer Application in Industry and Engineering (CAINE-2002)*, November 7–9, 2002, San Diego, CA, http://www.univ.edu/Research_Centers/NCACM.

Mitreski, K., Koneski, Z., Davcev, D., Naumoski, T., Mitic, V. and Sumka, S.: 1998, 'An ecological model of Lake Ohrid', in *Proceedings of the IASTED International Conference on Applied Modeling and Simulation*, Honolulu, 1998, pp. 32–35.

Mitreski, K., Davcev, D. and Koneski, Z.: 2000, 'Web-based pollution monitoring system for Lake Ohrid', in *Proceedings of the Third International Conference on Environmental Problems in Coastal Regions Coastal Environment III*, Las Palmas de Gran Canaria, 2000, pp. 77–84.

Mitreski, K. and Davcev, D.: 2003, '3-D visualization and analysis of the pollution sources in Lake Ohrid', *25th International Conference on Information Technology interfaces ITI 2003*, June 16–19, 2003, Cavtat, Croatia.

Molkenthin, F., Stump, S. and Appt, J.: 2002, 'Web-based data monitoring, analysis, reporting and management for field measurements', *Hydroinformatics 2002*, Cardiff, UK.

Open and Distance Learning Phare EU Center, http://odl-skopje.etf.ukim.edu.mk.

Panagaea Information Technology: 2002, *Information Management Strategy for the International Joint Commission Lake Ontario-St. Lawrence River Study*, May 2002, Chicago, IL, USA, http://www.great-lakes.net.

Sturm, B., Knauth, H. D., Theobald, N. and Wunsch G.: 1998, 'Hydrophobic micropollutants in samples of coastal waters', Fresenius-Zeitschrift 1998.

Umgeni Water, Environmental Report: 2001, http://www.umgeni.co.za/reports/environmental/.