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Technology-based management of environmental organizations using an Environmental Management Information System (EMIS): Design and development

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HIGHLIGHTS

- The proposed system can bridge the chasm between technology and public participation in environmental decision making in a more formal manner.
- The system promotes a holistic strategy for exploiting explicit and tacit knowledge to improve environmental management processes.
- The developed system facilitates environmental management to deal with more complex factors associated with issues of various natures.

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ABSTRACT

The adoption of Information and Communication Technologies (ICT) in environmental management has become a significant demand nowadays with the rapid growth of environmental information. This paper presents a prototype Environmental Management Information System (EMIS) that was developed to provide a systematic way of managing environmental data and human resources of an environmental organization. The system was designed using programming languages, a Database Management System (DBMS) and other technologies and programming tools and combines information from the relational database in order to achieve the principal goals of the environmental organization. The developed application can be used to store and elaborate information regarding: human resources data, environmental projects, observations, reports, data about the protected species, environmental measurements of pollutant factors or other kinds of analytical measurements and also the financial data of the organization. Furthermore, the system supports the visualization of spatial data structures by using geographic information systems (GIS) and web mapping technologies. This paper describes this prototype software application, its structure, its functions and how this system can be utilized to facilitate technology-based environmental management and decision-making process.

1. Introduction

The effective management of the natural environment greatly affects human societies and plays a significant role in conserving the world's natural resources contributing to a higher quality of human's life. The prospect of using information systems in environmental management has been upgraded lately with the development of new monitoring

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and management systems (Melville and Ross, 2010; Campos, 2012; Jiang and Pan, 2012). Furthermore, Environmental Informatics is an interdisciplinary branch of science that is rapidly gaining ground (Hilty et al., 2006; Huang and Chang, 2003). In this science, methods, techniques and disciplines of computer science are combined in order to analyze and elaborate information that contribute to an effective management and protection of the environment (Page and Rautenstrauch, 2001).

Environmental Management Information Systems (EMIS) are defined as organizational–technical systems for systematically obtaining, processing, and making relevant environmental information available in companies (El-Gayar and Fritz, 2006; Page and Rautenstrauch, 2001). Environmental Management Information Systems (EMIS) are defined as socio-technological systems with the aim to gather, process, and provide environmental information inside companies (Isenmann, 2008). In recent years, various Information Systems have been developed for the management and processing of the environmental information (Buhren and Decker, 2008; Mugerezi, 2006). Buhren and Decker (2008) describe the procedure of building an Environmental Management System, explaining its role and purpose in urban management, focusing on how the system can be used in the partner cities of the Sustainable Cities Programme (SCP). Mugerezi (2006) designed and implemented an Environmental Management Information System that covers the gathering of all relevant information for the Environmental Planning and Management (EPM) Process and includes the collection of information about various environmental issues. The Habitats Directive on the conservation of natural habitats and of wild fauna and flora, was adopted in 1992 (Council Directive 92/43/EEC, 1992). In accordance with this directive, Member States took measures to maintain or restore natural habitats and wild species and established environmental organizations with laws (Italy: Presidential Decree No 357 (1997), Greece: Law No. 2742 (1999), Spain: Royal Decree No 1997 (1995)) for managing protected areas and natural parks (Evans, 2006; Evans et al., 2013; Guignier and Prieur, 2010; Ostermann, 1998; Morris, 2011; Pinton, 2001; Rauschmayer et al., 2009). In Greece, according to the Law No. 2742/99 the principal goal of the environmental organization is the management of the nature and the landscape, as well as areas designated as Special Areas of Conservation (Papageorgiou and Vogiatzakis, 2006; Papageorgiou and Kassioumis, 2005). Also, according to the same law, environmental organizations are responsible for collecting and elaborating environmental data and for creating and managing relational databases.

Considering the development of information technology and the growing amount of information about the environment, it becomes necessary for an environmental management organization to utilize an information system that will manage all relevant environmental information and also will be used as a tool for a better and more efficient management of the protected area and the natural resources (Graham et al., 2003; Worboys et al., 2001). This paper describes an environmental management information system of this kind, which was developed using several technologies and programming tools. The system combines characteristics of Environmental Management Information Systems (EMIS) and Human Resource Management Information Systems (HRMIS). HRMIS are Information Systems that provide information used by human resource management in decision making (Sims, 2007; Ngai and Wat, 2006). In the following sections, the functions of the prototype application and the development methodology will be discussed in more detail. Furthermore, an example study is then used to show how this software system can be applied.

2. Materials and methods

2.1. Requirement analysis

The first stage in designing the system is to define the kinds of data that is going to be stored in the database, and to specify the information that EMIS system is going to manage. This step is of primary importance so as to define the modules of the software and its structure (Elmasri and Navathe, 2011; Maciaszek, 2007; Ramakrishnan and Gehrke, 2003).

According to the article 7 of the Directive of the European Parliament on public access to environmental information (Directive 2003/4/EC, 2003), which amended the previous directive on the freedom of access to information on the environment (Council Directive 90/313/EEC, 1990) Member States shall ensure that environmental information progressively become available in electronic databases which should be easily accessible to the public through public telecommunication networks. Also, according to the article 2f of the same directive the system must provide information about the environmental data of the organization, regarding measurements of air pollution (e.g. CO, NO), water pollution (heavy metals, Biochemical Oxygen Demand etc.) or other type of environmental data.

Except for fulfilling the legal obligations of the environmental organization, this information can also be utilized in making decisions and taking measures about environmental issues and also sending documents and reports to the local and the governmental authorities (Ministry of the Environment, Judicial Authorities). These data are valuable for performing environmental risk assessment and developing risk management strategies (Lener et al., 2013; Smith, 2013). The system, also manages information about the protected species of the organization's jurisdiction area, regarding methods of monitoring and registering the biodiversity in the protected area (Danielsen et al., 2000).

Also, it is necessary the system to provide information about the staff of the organization, helping in human resources management and in project management, such as: education, curriculum vitae, residence, contact information, hiring data (hire date, salary, position, etc.) and information regarding user's registration to the system (Gerber et al., 1995). The system manages geographic information that can be displayed on geographic web maps accompanied by descriptive data. The visualized spatial data are helpful for environmental project management and planning (Bishop and Lange, 2005).

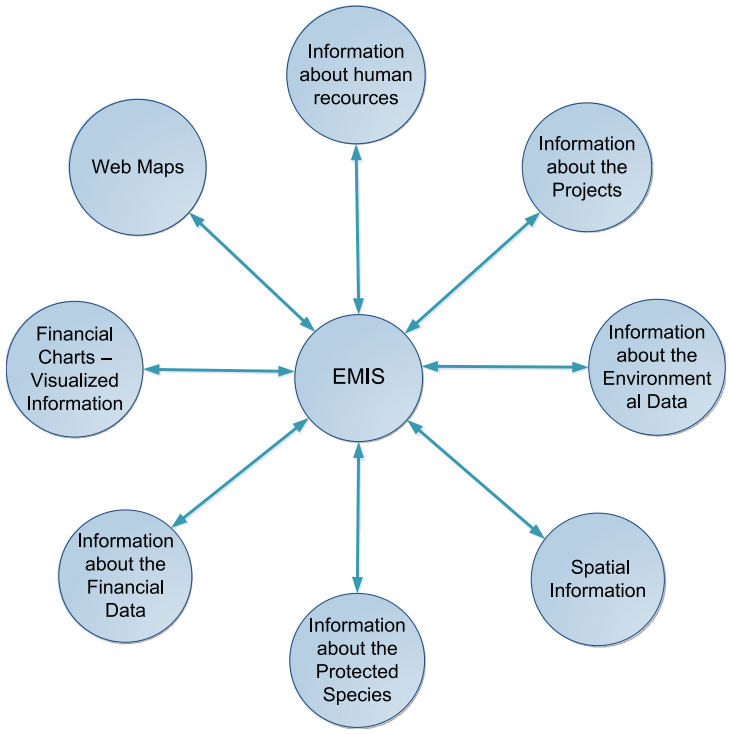

Fig. 1. Information of the EMIS system. The bidirectional arrows represent the reciprocal relationships between the system and the information. The EMIS system manages and provides information to the user, and the user manages and elaborates information in EMIS.

In addition, the system facilitates project management by monitoring the implementation and providing information about the assigned environmental projects. Moreover, information about the financial data of the organization and visualized financial data on charts, regarding revenues, expenses of the organization help in economic planning, decision-making and financial management (Tietenberg and Lewis, 2000) (Fig. 1).

2.2. Implementation technologies

The software implementation section describes the appropriate technologies that were utilized for designing the forms of the application and building the whole architecture and the structure of system, such as programming languages, a database management system, programming tools and other technologies.

Recent advances in database technologies and new advanced database architectures can be used to store and process the increasing amount of environmental data (Pokorný, 2006). The system was developed using Microsoft SQL Server 2008 Release 2 as a Database Management System. The type of the database that was chosen for the application is a service-based database which allows the access for multiple concurrent users and multiple workstations over a network or the internet and can be used on the official website of the organization where citizens will have the opportunity to have access to environmental data (Mistry and Misner, 2010). The information system was implemented using Visual Basic 2010 as a programming language for writing code which is an object-oriented programming language that allows the programmer to use objects (Data Access Objects, ActiveX Data Objects, etc.) to create applications with a Graphical User Interface (GUI) (Zak, 2012; Sheldon et al., 2010). Microsoft. NET Framework 4.0 was used as a framework for developing the application. NET Framework 4.0 includes a large library of coded solutions to common programming problems and a virtual machine that manages the execution of programs. Also, ArcGIS Flex API which is an application framework developed by ESRI, using the technology of ArcGIS Server REST services and ArcGIS Online, were used in order to create an interactive GIS RIA (Rich Internet Application) mapping application which includes many core Web GIS mapping functionalities (Fu and Sun, 2010; Yuan et al., 2011). Microsoft IIS (Internet Information Server) was used as a Web Server (Cochran and Forsyth, 2008). Extensible Markup Language (XML), which is a flexible text format derived from SGML (ISO 8879), was used for configuring Flex Viewer for exchanging data on web maps.

The system's architecture includes 4 layers: Database Tier, Business Logic Tier, Web Server Tier and Client Tier. The Client Tier (user interface) consists of three modules: the "Web Forms" where web maps are displayed, the "Data Insertion Forms" where client can view information and insert data to the system and the "System Administration Forms" where the administrator manages the application and users' system registration. In the Web Server Tier, IIS handles requests from the clients and send them to the Business Logic Tier for being processed. In the Business Tier, the application server uses

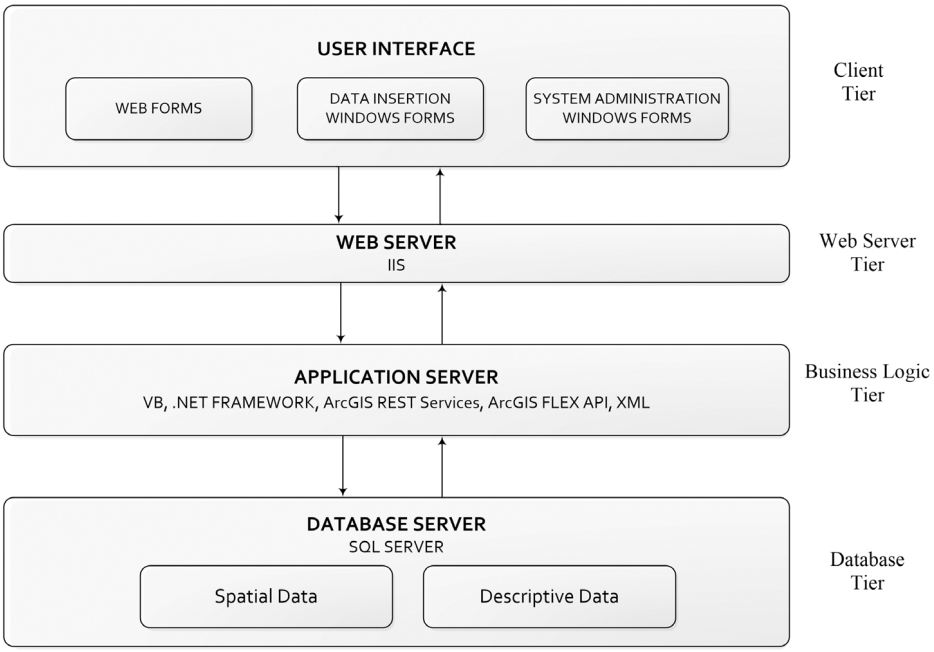

Fig. 2. System's 4-tier architecture.

technologies (VB, .NET Framework, ArcGIS Server REST services and Flex Viewer, XML) to processes individual user requests and to send them to the Database Tier where the database server (SQL Server) is responsible for storing and processing spatial and descriptive data (Fig. 2).

3. Results and discussion

3.1. Overview of EMIS

The developed system consists of six modules: Human Recourses and Project Management, Environmental Data, Financial Data, Protected Species, Spatial Data and Web Maps. The proposed high level model of using EMIS is based on the concepts and techniques of project management, facilitating the stages of the project assignment and monitoring of the implementation progress, through the inserted information in the relational database of the system (reports, observations, schedules, measurements, etc.). Establishing a robust and reliable communication and data exchange between the supervisor and the scientific staff during the implementation of the project plan is essential for achieving a successful outcome and for discovering and resolving possible problems and drawbacks in time or making decisions about rescheduling or abandoning a project if the cost became too high to be afforded or if it cannot be implemented for other reasons (Gido and Clements, 2012). The inserted data and reports, which analyze and interpret the findings, are valuable for performing environmental planning strategies, financial management, risk management, monitoring protected species and pollution factors in order to preserve the natural resources of the protected area and to prevent further environmental degradation (Fig. 3).

3.2. Web maps and spatial data

Flex technology was used to develop a Web GIS mapping application, in order to display the web maps of the organization with visualized spatial data and perform some core GIS mapping functionalities: data display, layer controlling, map navigation, query and search, measuring lines and areas, and data editing (Kehe et al., 2013; Strode, 2012).

In order to present an instructive example of using the EMIS information system, a pilot area was chosen. The area of jurisdiction of the environmental organization was selected to be a region in Magnisia in Greece. This area was chosen because includes the area of an existing Greek Environmental Management Organization of Lake Karla – Mavrovounio – Kefalovryso (Evans, 2012; Zalidis et al., 2004). This area is shown on the map by a red line border, which was added as a layer and includes the locations: Volos, Lake Karla, Mavrovounio, Agria, Sesklo, Kanalia, Xrisi Akti, Stefanovikio, Velestino, Kefalovryso, Agios Georgios, Rizomylos, Kerasia, Portaria. Also, for the purposes of presenting the application, some spatial and tabular data were developed and visualized on the map of the organization as layers, which are related to the

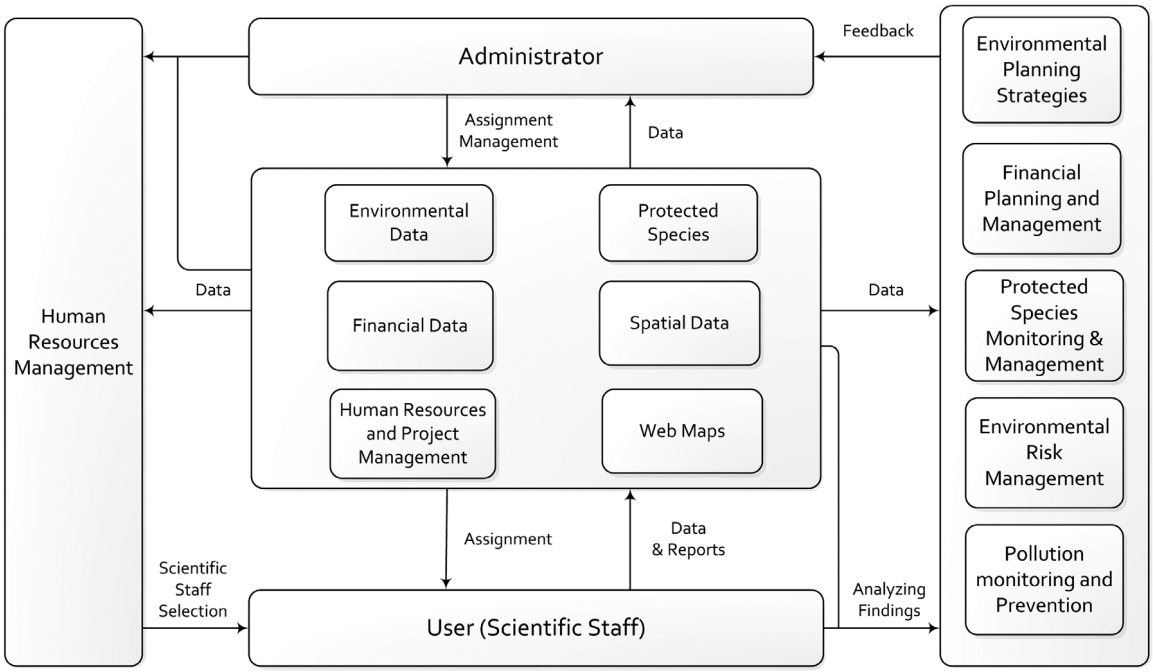

Fig. 3. Overview of the proposed high level model of using the system.

Table 1
Organization's infrastructure.

	Id	Data layers	Place	Longitude	Latitude
Stations	1	Buildings in the central station of Volos	Volos	22,957582	39,361315
	2	Buildings in the substation of Velestino	Velestino	22,749830	39,385882
	3	Buildings' infrastructure of substation in lake Karla	Stefanovikio	22,755340	39,466271
Observation points	1	Monitoring the quality of water in Pagasitikos Gulf	Volos	22,929634	39,355411
	2	Monitoring the air pollution in 2nd industrial area	Velestino	22,783635	39,396208
	3	Monitoring the Natura protected area in Portaria	Portaria	23,007700	39,392215
	4	Monitoring the quality of water in lake Karla	Kanalia	22,885206	39,480612
	5	Bird observatory of Karla Lake	Stefanovikio	22,785290	39,466616
Vehicles	1	Vehicle for the personnel in the region of Volos	Volos	22,959217	39,359244
	2	Vehicle for the personnel in the region of Velestino	Velestino	22,744783	39,381963
	3	Vehicle for the personnel in the region of Karla Lake	Stefanovikio	22,750252	39,462898
Constructions	1	1st Karla Lake barrier facilities	Kanalia	22,861369	39,472838
	2	Barrier facilities from the river Peneus to lake Karla	Stefanovikio	22,814080	39,447461
	3	2nd Barrier facilities in Kanalia	Kanalia	22,864369	39,494984

infrastructure of the organization (buildings, vehicles, observation points, constructions) and to the assigned environmental projects in that region. The data regarding the organization's infrastructure are shown in Table 1 and in Fig. 4.

3.3. Human resources and project management

The system manages human resources data (educational data, contact information, payroll data, previous experience, social insurance, position, etc.) and project data (title, description, supervisor, cost, spatial data, uploaded reports, observations, schedules, etc.) useful in human resources management, project management, payroll management and financial management. In project-oriented organizations Human Resources Management (HRM) is essential to the success of the organization (Rose, 2007). In this module, the administrator assigns tasks to the scientific staff and monitors their implementation and informs the central administration about their progress, the final results and the possible problems during the implementation and also about the factors which are affecting project success (Baker et al., 2008; Belout and Gauvreau, 2004). These data provide the required documents to the administration to take decisions or measures about environmental issues. The administrator and the users interact asynchronously through the system on the network, storing, manipulating data in the relational database, during the project management process (Kerzner, 2013).

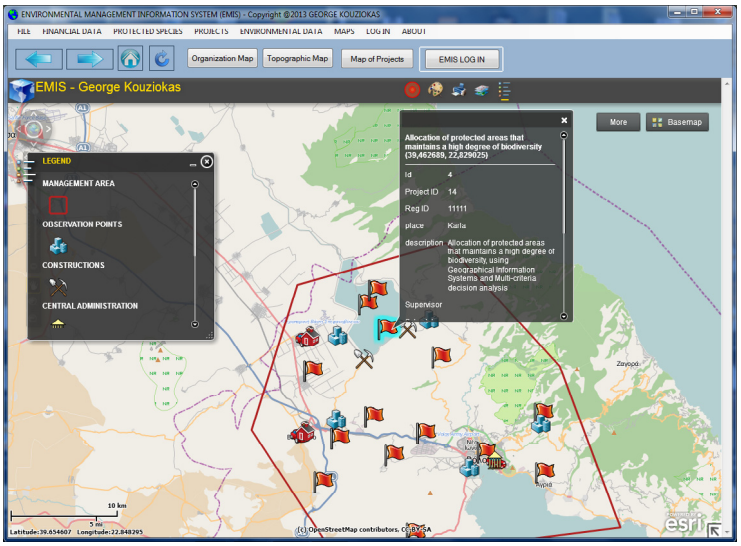

Fig. 4. Visualized data on the web map, using the OpenStreetMap as a base map. Different symbology was chosen for the buildings of the organization (red house icon for substations, yellow icon for the Central Station), for the observation points of the organization (blue building icon), for the projects (red flag icon), for the constructions (construction icon) and for the vehicles of the organization (red vehicle icon). Furthermore, when an assigned project is clicked on the map, a label pops up and shows some more information such as: place, a short description, the supervisor of the project and a link to a web address for more information about the project. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.4. Environmental data

In this module of EMIS environmental data are inserted (type of measurement, date, place, longitude, latitude, value, unit, observations, etc.) regarding air pollution (e.g. CO, NO), water pollution (heavy metals, etc.) or other kinds of environmental data that are important to be measured for the health of the ecosystem of the protected area (Parrish et al., 2003). The interpretation of measured data is much easier when having them organized in a searchable relational database. This information can be used by the organization in order to assess ecological and human health risks (Suter, 2006) and take measures for the survival of the ecosystem and also to send reports and documents to the authorities (Paavola, 2004). Preventing further environmental degradation, increasing environmental protection and minimizing further negative impacts to the ecosystem plays a significant role in natural conservation (Glasson et al., 2013; Morris and Therivel, 2001; Treweek, 2009).

3.5. Protected species

This module of the system provides information about the protected species of the organization's territory. The inserted data include reports, data about the protected species (scientific names, description, photos, population, etc.), observations, and information about the exact place where they live (providing the measured longitude and latitude). Monitoring the survival status of the protected species, interpreting the findings and taking preventive measures to preserve them when it is necessary, is one of the primary goals of the environmental organization and these data can help in this direction (Naughton-Treves et al., 2005).

3.6. Financial data

Financial data are elaborated through this module regarding detailed information about the revenues (private donations, state financial subsidies, etc.) and expenses (scientific equipment supplies, monitoring fauna expenses, buildings maintenance, etc.) of the organization. The inserted data can be visualized by the submodules of the system "Revenue Chart", "Expense Chart" and "Comparison 3D Diagrams". The objective of this module is to support and enhance the financial management and planning of the organization and facilitate the decision making, regarding financial cuts or reforms depending on the revenues and the expenses of the organization (Armsworth et al., 2011; Laycock et al., 2009) (see Fig. 5).

3.7. Technology-based environmental management

EMIS deals with environmental issues as projects and incorporates project management techniques in environmental management. The difference with classic project management is that every environmental issue (project) does not have the

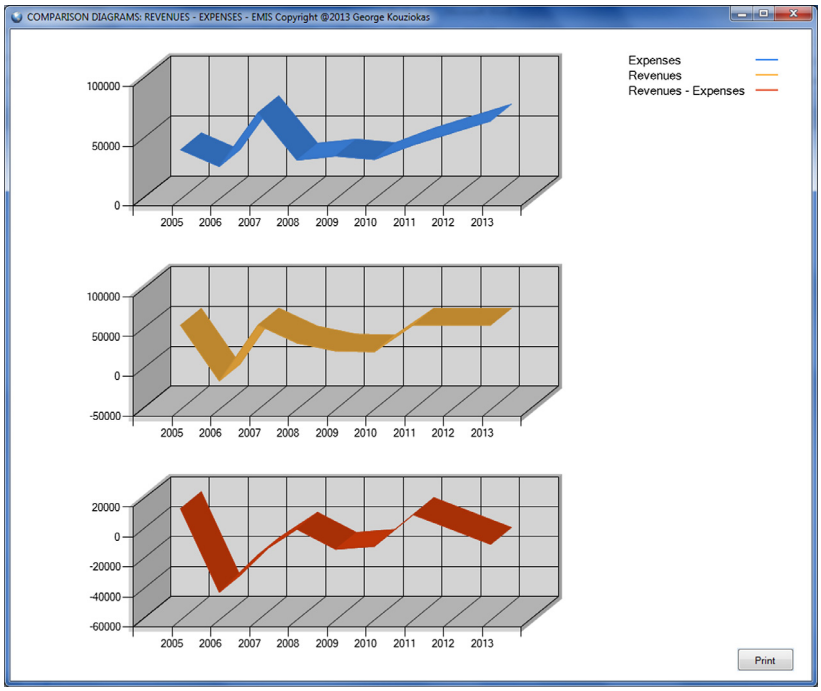

Fig. 5. 3D comparison financial data diagrams.

meaning of a classic project but of an environmental task that must be handled. That way every environmental problem, anomaly or issue is confronted in the same way in the system, holistically, as technology-based management principles demands. Technology-based management has its roots in knowledge management relying heavily on ICT (Ming Yu, 2002). By using techniques of technology based management, EMIS promotes a holistic strategy for exploiting explicit and tacit knowledge to improve environmental management processes and resolve any environmental issues.

The project-based approach that EMIS uses can help bridge the chasm between technology-based management and public involvement in environmental decision making. For example data of volunteer environmental monitoring can be stored and processed in the relational database, involving citizens more directly in environmental decision making according to the principles of democratization (Pretty et al., 2007). Also, cooperative knowledge processing and the recognition of interdatabase dependencies is the key technology for intelligent organizations (Kirn & O'Hare, 2012). The proposed system is designed to have many degrees of freedom regarding the nature of the 'environmental issues' that has to be addressed in the context of environmental management. For example, a 'project' could be an environmental measurement regarding pollutant factors in order to assess ecological and human health risks, or analyzed data for the development of environmental performance indicators (EPIs) or a public participation initiative in environmental decision making. This facilitates environmental management to deal with many more factors and more complex associated with environmental issues of various natures.

3.8. Discussion—EMIS in environmental management

This paper makes a contribution in providing spatially explicit environmental data sets and an extendable solution framework that allows environmentalists to investigate multidimensional factors of environmental management and planning in protected areas and how they can be related to each other.

EMIS can face the lack of detailed environmental information, since multidimensional records are often the missing key in environmental planning, resulting in difficulties and misleading directions in analysis and interpretation of environmental data. The GUI interface of EMIS has hybrid nature combining the advantages of a web-based interface for illustrating interactive customizable web maps and the other web content and the flexibility of windows-based interfaces for achieving easier insertion and management of environmental data.

With EMIS functions it is the first time that so many factors are taken into consideration for environmental management and planning, as a holistic approach, considering the human–natural environment interactions as a system with multiple dimensions (economic, ecosystemic, pollution factors, etc.). This way every dimension can be managed and monitored through one information system. Otherwise multiple applications would be needed with the disadvantage that no correlation would exist between their data such as: a system for managing human resources (HRMIS), a system for

monitoring the flora and fauna, a system for inserting and managing crucial data of the protected species, an accountant system for economic data, a GIS system for visualizing and serving spatial and descriptive data and a project management information system.

The benefit of that holistic approach is that when a dimension of the system changes the impact on the other dimensions can be observed and managed, through EMIS, in order to reach holistic management goals (Schultz, 2011). By using different information systems with no correlated data between them, the environmental organization will not able to detect immediately the actual effects of the occurred environmental issues on the ecosystem and find the correlated factors to solve them in a manner that will have the minimum cost for the natural resources.

EMIS was designed by taking into consideration specific factors regarding the European legislation on the environment aiming at managing and preserving the protected areas. Unlike other environmental information systems, EMIS focuses on public organizations established according to EU directives (Council Directive 92/43/EEC, 1992; Directive 2003/4/EC, 2003; Council Directive 90/313/EEC, 1990) for preserving and managing the natural resources. There is no literature reviewed in this article for designing an information system of this kind.

The structure of the developed system, that supports the collection of almost any kind of environmental data, can confront the complexity and the size of the collected data, facilitating the new analytical approaches and methods of environmental information management and analysis (Michener et al., 1994).

Processing and analyzing the data stored in the database, can facilitate the development of environmental performance indicators (EPIs) used internally for environmental management and externally for public reporting (Scherpereel et al., 2001). The collected data in EMIS are always available for statistical analysis and interpretation so that environmental problems and assessment risks can be handled (McBean and Rovers, 1998; Clark, 2007; Brown and Mac Berthouex, 2002). EMIS contributes to pollution monitoring by processing measured environmental data, since many kinds of factors can influence the health of the ecosystem, such as air (CO, NO, etc.), soil or water pollution factors (Gilbert, 1987; Barnett, 2005). Also, EMIS can provide relational data about water quality which are fundamental to hydrology and water resources management (Horsburgh et al., 2008).

The role of Information Systems in helping organizations develop ecological sustainability is very important and EMIS can contribute in this direction (Chen et al., 2008; Tomlinson, 2010). Spatial Data module of EMIS visualizes spatial data and represents raw data on web-maps which is a very significant part of exploratory data analysis (Kanevski and Maignan, 2004). Moreover, management decision assessment frameworks regarding the monitoring of protected areas always depend on the collected environmental data, processed and interpreted by the scientific staff (Danielsen et al., 2005). The gathered data are also useful for decision-making, regarding the adoption of environmental supply chain strategies by the environmental organization and also for suggesting companies about how they can integrate environmental and supply chain practices, to be environmentally friendly (Handfield et al., 2005). Protected area management enhancement can be achieved by improving the understanding of the causes and the policies of the social, economic, and ecological values of protected areas (Prato and Fagre, 2005).

Also, EMIS provides the appropriate information towards facilitating methodologies for assessing the effectiveness of environmental management in protected areas (Hockings, 2003). Information about the human resources (education, previous working experience, etc.) in public organizations contributes to a more flexible and effective management schema by recruiting the most adequate staff with the necessary skills to carry out the assigned tasks (Pynes, 2008). Furthermore, the system facilitates environmental project management by controlling the assignment process and project costs, monitoring project implementation, managing a large amount of environmental information through the relational database (Table 2).

4. Conclusions

The adoption of information systems in environmental management and planning has become an increasingly significant demand nowadays with the rapid growth of environmental information. In this paper, an Environmental Management Information System was designed and implemented to provide a systematic way of collecting, managing and elaborating environmental data in a relational database. Also, the system was developed aiming at the modernization and computerization of the environmental organization, by providing a secure project management process and data collection, ensuring the gathering of reliable environmental data verified by the members of the scientific staff that collect them. The main idea of developing the modules of the system is to encompass multiple aspects that influence, directly or indirectly, the environmental management process such as pollutant, economic, human and natural factors, incorporating spatial characteristics utilized for locating the collected data in the web maps.

The provided information can be utilized by the environmental organization in multiple ways, such as managing environmental projects and financial data, adopting reforming measures, monitoring environmental data (e.g. Measurements of pollution factors) and information about the protected species, taking preventing measures and sending reports to the authorities.

Consequently, the findings presented in this paper suggest that EMIS can be utilized in fulfilling anticipated environmental objectives of an environmental organization by collecting, storing and processing multidimensional environmental records towards applying effective environmental management policies and planning strategies.

Table 2
Modules of EMIS system and its functions and how they contribute to an effective environmental management.

Module	Functions	Contribution
Environmental data	Measurements, observations of environmental data such as CO, NO (assessment of air pollution), BOD, COD etc.	Analysis and interpretation of environmental data. Reporting the results and the assessments of the measurements at the local authorities and the Ministry of the Environment when values of measurements exceed the limits of the measuring parameters. Taking decisions to prevent further pollution and environmental degradation, and to reduce negative impacts to the environment (Sugumaran et al., 2004).
Protected species	Information and reports about the protected species of the organization's territory.	Monitoring the protected species and their population in order to make decisions about taking preventive measures for their survival (Morris et al., 2002; MacKenzie et al., 2003; Urbano et al., 2010; Danielsen et al., 2003).
Financial data	Financial data of the expenses and revenues of the Environmental Organization.	Monitoring the financial data and performing financial cuts and reforms if needed, and economic planning in order to make a sustainable budget for the Environmental Organization (Schaltegger and Synnestvedt, 2002).
Human resources and project management	Personal, educational, hiring data of the personnel, registration to the system, salary etc.	Making decisions in hiring staff with specialists that the organization needs, and issues about Human Resources Management (assigning projects to the staff with relevant experience and education, etc.) (Laudon and Laudon, 2012; Belout and Gauvreau, 2004; Belout, 1998).
Spatial data	Storing spatial data and extracting these data from the database in order to display them on the map.	Visualizing spatial data when is needed for spatial planning, project management, environmental planning and decision making process (Kanevski, 2010; Beunen, 2006).
Web maps	Displaying web maps of the organization's territory containing data of the Organization's Infrastructure, the assigned tasks and environmental data.	Using Web Maps with visualized spatial data of the facilities of the Organization, environmental data, protected species, and assigned tasks to perform future planning and make decisions about environmental issues (Culshaw et al., 2006).

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