Cooperative WebGIS interactive information systems for water resources data management

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Abstract The dissemination and management of water related data using web-based information systems is a promising technological approach for sharing knowledge both with water users and the general public. These synchronous information systems facilitate spatial data and descriptive information sharing over the cloud and are accessible through common web browsers. The data harmonization is based on standards satisfying common data formats and transmission protocols. In this paper, two cooperative web-based information systems are described. The first one serves spatially distributed and descriptive information of national databases related to transboundary aquifers of the African continent. The second is a holistic information system for providing near real time alerts of flood events for the Greek part of the Strymon transboundary river basin. In both cases, all the included data, as well as metadata and auxiliary information, are available to the stakeholders involved and they satisfy inter-operability requirements.

Key words WebGIS; cooperative information systems; transboundary aquifers; Africa; transboundary river basin; Strymon River; Greece

INTRODUCTION

Hydrological data and reliable information on water resources, both in terms of water quantity and quality, are the key prerequisites for successful development of mathematical simulation models and sustainable water resources management. Regardless of the model's structure, complexity and the integration capacity of the equations simulating the hydrological cycle, the model's output depends on the availability and accuracy of spatially- and temporally-distributed hydrological data. With this in mind, international and national databases on water resources have been developed in the past few decades and are mainly available in developed countries. These databases contain observation data from monitoring networks (NCDC, 2011), meteorological gauges (HYDROSCOPE, 2010) and remote sensing products (USGS, 2011), as well as coverage data, such as topographic relief, land use and soil textures (Panagos *et al*., 20012). The importance of sharing information and datasets is greater when dealing with internationally shared river basins and transboundary aquifers.

The development of cooperative databases has been fostered by the improvement of Geographic Information Systems (GIS) technology which, among its other capabilities, combines the storage of descriptive and observational information with coverage characteristics. Moreover, the relatively recent emergent technology for broadcasting spatially structured data on the Internet (Neteler & Mitasova, 2008) reveals the increased need for sharing stand-alone knowledge on hydrological processes, potential changes due to climate variations, land use alterations or human interventions and their impacts. The simultaneous development of distributed computing technologies and high speed Internet advanced the progress of web-based GIS technology, namely WebGIS. Both open source (OS) and commercial (COM) systems are being routinely utilised, not only for sharing spatial datasets, but also for advanced geoprocessing functions across the web (Kiehle *et al*., 2007). However, access to these datasets is not always a straightforward procedure and the coupling of data records coming from different sources requires data format homogenization techniques. Also, in order to satisfy data interoperability, cooperative WebGIS systems should be based on international communication standards, such as those proposed by the

Open Geospatial Consortium, OGC (OGC, 2013). The INSPIRE Directive of the European Community (EC) (EU, 2007) for establishing an infrastructure for spatial information to support EC environmental policies is a good example of promoting harmonised data, since it triggers the creation of a European spatial data infrastructure which delivers integrated spatial information services linked by common standards and protocols to users.

The aim of this research is not only the construction of GIS-based comprehensive databases, but also the broadcasting of spatially structured data on the Internet. Two specific case studies are described concerning the use of open source (OS) and commercial (COM) WebGIS technologies. The developed OS geoinformation system serves spatially and descriptive national databases related to transboundary aquifers of African countries, where authorized users are enabled to update the data through the developed platform. The COM WebGIS application is a holistic information system for providing near real time alerts of flood events for the Greek part of the Strymon transboundary river basin, where data and services are available and are for use by water authorities.

WEBGIS INTERACTIVE INFORMATION SYSTEMS

With the continuous emergence of new Internet technology, GIS are becoming more open and accessible, thereby facilitating the democratization of sharing spatial data, open accessibility, and effective dissemination of information (Dragicevic, 2004). However, it was only in 1993 that Xerox Corporation launched the first experimental tool for interactive spatial data exploration over the web, while the first distributed library service for spatially referenced data was established a year later. In the late 1990s, the development of the Extensible Markup Language (XML) as a standard for data interchange on the Internet allowed geographic information to be easily translated into graphics. This meant that two-dimensional graphics maps and relative geographic information on both the spatial and non-spatial properties of geographic features could be projected by common web browsers (Karakos *et. al*., 2003). These early implementations were mainly focused on the distribution of static maps, interactive maps with pan-identify-zoom features, support for client/server designs, and advanced cartographic and geo-visualization tools (Kraak & Brown, 2001). In the early 2000s, WebGIS applications were able to provide more sophisticated cartography and spatial visualization features (Juba *et al*., 2007) as well as interactivity characteristics with map queries functionalities. The University of Minnesota Mapserver OS platform was one of the first systems integrating web mapping and querying capabilities, using PostGIS spatial database extender for its connection with the PostgreSQL database (Brovelli & Magni, 2003).

At the same time as the foundations of web technology matured and WebGIS systems were flourishing, there was a need for improved spatial data interoperability and superior graphic image outputs. Peng & Zhang (2004) proposed the geography mark-up language (GML) as a coding and data transmission mechanism to achieve interoperability, scalable vector graphics (SVG) to enhance the quality of the data display over the Web, and OpenGIS Web feature service (WFS) specifications mechanism to improve access and retrieval of spatial data. The problems arising from the lack of cooperative GIS systems communication and data homogenization, which used different formats and different projection systems, were overcome by the development and implementation of the standards for geospatial content and services, GIS data processing and data sharing. The main standards for cooperative WebGIS are provided by the Open Geospatial Consortium (OGC) and currently almost all web-based geographical information systems have embedded standards such as SVG, WFS, GML, XML, web map service (WMS) and Keyhole Markup Language (KML). KML is a file format for displaying geographic data in Earth browsers developed by Google, such as Google Earth and Google Maps, but it also can be interpreted by any other modern information system. XML is the metadata standard proposed by the INSPIRE Directive, i.e. the syntax of metadata is specified in XML format, and is readable by any information system.

A key function of OGC standards is the integration of different, already existing systems and thus geo-enabling the web. Web services providing different functionality can be used simultaneously to combine data from different sources (Dunfey *et al*., 2006). Thus, different services on distributed servers can be combined for “service-chaining” in order to add additional value to existing services. Providing a wide use of OGC standards by different web services, sharing distributed data of multiple organisations becomes possible.

COOPERATIVE WEBGIS DATABASES – CASE STUDIES

Inventory of transboundary aquifers in Africa

The principle aim of this geo-referenced information system developed for the transboundary aquifers in Africa was to provide appropriate tools under a web-based platform for water management institutions in the region (Fig. 1). These tools would enable them to implement sustainable forms of utilisation, management and protection of transboundary groundwater resources. The logical architecture of the system is based on the principles of: (i) direct access to the transboundary aquifers database by water users through a Graphical Users Interface (GUI); (ii) real time updating of the database by the national expert responsible for each country’s data inventory, without the need of an information technology (IT) administrator; and (iii) public participation by allowing users to provide general comments, or comments related to specific geolocations and to specific database field values, on the aquifers that are dynamically overlaid on the base map.

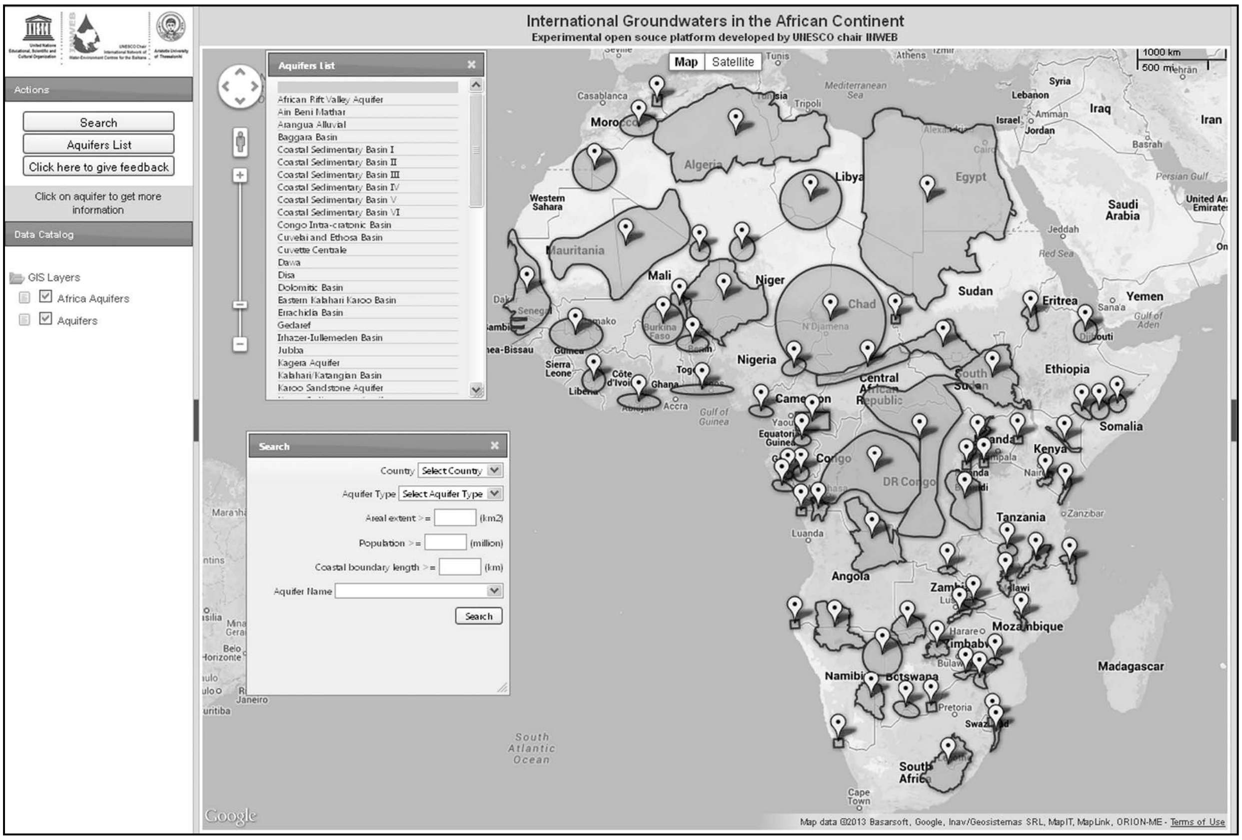

Fig. 1 Web-based geo-information system for disseminating information related to transboundary aquifers in Africa.

This OS interactive information system couples a Google Cloud database, in which all the relevant descriptive, spatial (vector and raster) and tabulated information is stored, with Google-Fusion Tables technology in order to spatially distribute the information on the Africa region. Custom programming with JavaScript and HTML5 web developing languages was used for the creation both of the GUI of the platform and the linkage with the database. Both these languages facilitate sending requests and exchanging data asynchronously between client and server to avoid full page reloads. The homogenization of different vector files representing the aquifers (namely shape files) and their projection to a common projection system (namely WGS 84), was *a priori* conducted with GIS tools.

The data included in the platform were compiled from reports and descriptive questionnaires provided by the UNESCO Regional Centre for Shared Aquifer Management (RCSARM) in Tripoli, Libya, and the UNESCO International Groundwater Resource Assessment Center (IGRAC) in the Netherlands. (UNESCO/IGRAC, 2012). A total of 71 transboundary aquifers were previously identified by IGRAC. The information gathered was related to: (i) the aquifers' general characteristics, such as the hydrogeological type, predominant lithology, areal extent, mean and maximum thickness, population in the area, transboundary boundary length and dominant groundwater flow direction; (ii) the aquifers' hydrological characteristics and groundwater use, such as the average annual and seasonal distribution of rainfall, level changes, total available non-renewable groundwater reserves, total groundwater abstractions, average conductivity, transmissivity and storage coefficient, as well as water use proportions by sector; (iii) the aquifers' monitoring networks, such as number of gauges, type of measured parameters, frequency of measurements; (iv) the importance of the groundwater uses; (v) the problems observed in transboundary groundwater; and finally (vi) the management measures, i.e. the recommendations for mitigating the degradation of the water quality and quantity.

The specific information system enables the visualization of an aquifer's spatial extent and projection over the African continent, the aquifer boundaries and the project countries, together with a comprehensive legend tool providing information about the type of aquifers and the data availability. The thematic layers can be overlaid on four different base maps provided by Google. Furthermore, different alternatives for obtaining and retrieving data have been created. This means that the data are presented both in summary form, i.e. essential data on each aquifer based on excerpts from the questionnaires, but also the primary information sources, namely the questionnaires on the aquifers and the national reports for the groundwater status of each country, can be downloaded in full. The filters of the integrated customized search module also enable the identification of aquifers according to specific criteria, e.g. porous aquifers whose extent is smaller than a specific value and/or where the regional population is greater than a second specific value, and/or where water abstractions are less than a third specific value. The results of the search process are directly linked to the overlaid layers, i.e. only the aquifers which fulfil the search criteria are shown on the map.

Strymon transboundary river basin flood alert system

The EU Floods Directive and Desertification Convention require reliable and continuous monitoring of water quantity data in order to support decision making for the prediction of floods and erosion, focusing primarily on civil protection. With this in mind, the developed application couples water quantity monitoring telemetry systems with GIS-based map server technologies for the near real time prediction of and warning about flood events in the Strymon internationally shared river basin, Fig. 2. In this basin Bulgaria, Serbia and FYR Macedonia are the upstream countries and Greece is the downstream country.

Data related to the administrative, environmental, hydrological and topographic characteristics of the Greek part of the basin have been collected, analysed, homogenised and stored in geodatabases. These are the common data storage and management framework for spatial information. The geodatabase infrastructure was built in the Microsoft SQL Server 2008 database system, which is inter-operable with the ArcGIS Server, developed by ESRI, for the dissemination of information on the Internet. Water levels, velocities and discharges are monitored by a dense telemetry network and are transmitted and stored in the database for broadcasting in graphical and tabulated form through the WebGIS system. The alert thresholds of the measured values are predefined and extreme fluctuations of the values are shown using an indicative colour scale, i.e. green colour for normal values and red for increased measurements for the relevant stations.

Furthermore, the implementation of a relational database management system (RDBMS), which is related to geographical objects through geodatabases, converted the system into an organized collection of geographic data designed to incorporate, store, update, manage and properly allocate information. This means that each monitoring station is connected to a number of spatial elements, such as the downstream water body, inhabited areas, farms and regions under environmental protection located within a specific range. Whenever the alert thresholds values are reached, the areas of influence are highlighted on the web-based information platform. Thus, this holistic web system provides flood warnings and allows the authorities to play a contributing role and to confront extreme situations with increased efficiency.

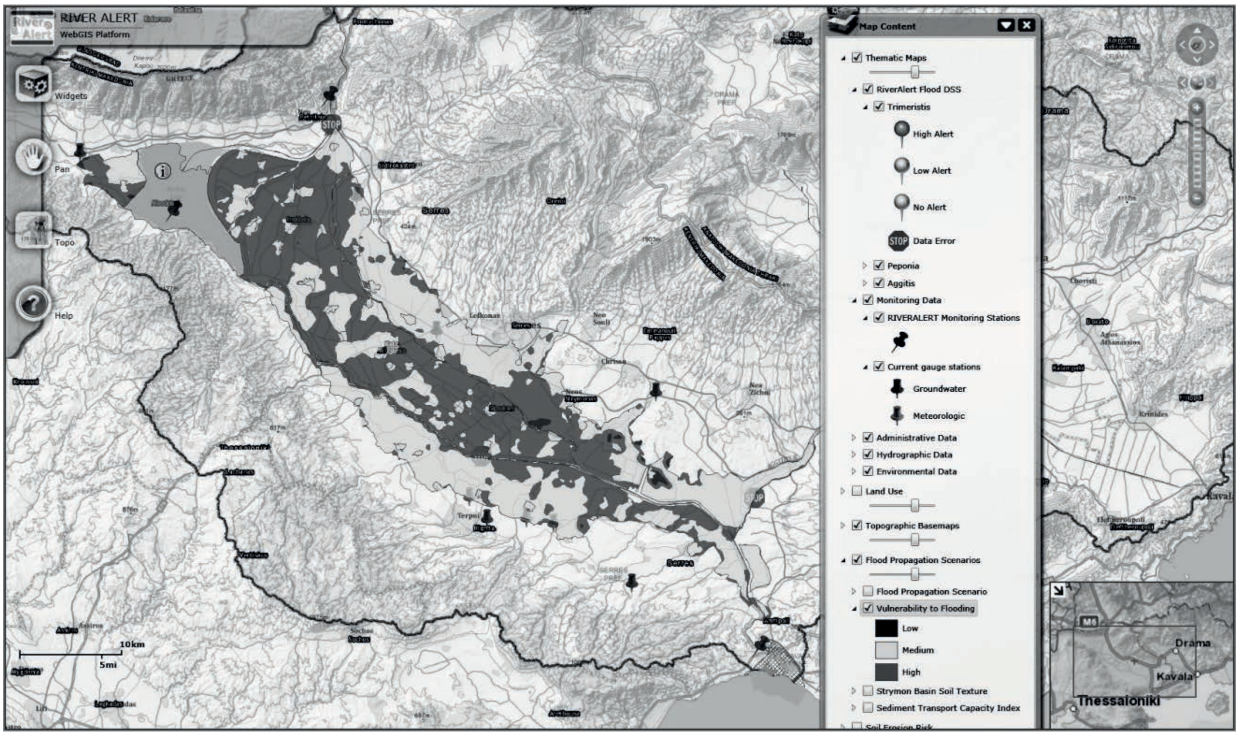

Fig. 2 Illustration of thematic layers such as monitoring stations and their operational status, hydrographic network and the area's vulnerability to floods for the Greek part of the Strymon transboundary river basin.

The spatial and descriptive information can be fully accessed by water users; however the observation data has been classified into accessibility levels. Users with certain privileges can retrieve whole datasets, while members of the general public are only authorised to retrieve descriptive diagrams. In addition, all the spatial information is available in the form of map services in order to potentially be integrated to other geoinformation systems.

DISCUSSION

Incorporating pioneering and modern technologies plays an important role in broadcasting spatially structured data on the Internet and in disseminating the stored information via common web browsers. WebGIS information systems exploit the capabilities of GIS tools for publishing spatial (vector and/or raster) data attributed with descriptive information on the Internet. Open Source and commercial information systems both have their own strengths and limitations, enabling the integration of a number of services and programming languages in order to both manage and publish water related datasets in the cloud.

In this paper the progress made in developing such collaborative tools is shown in case studies from southeastern Europe and Africa. In both cases, comprehensive databases, including common data in terms of descriptive information and format of elements and numeric values, have been constructed. By using specially tailored cooperative information systems, the data collected from different countries were communicated to stakeholders at a local level in such a way as to facilitate their involvement in the decision making process. Furthermore, part of the data included in the interactive information systems has been translated to web map services for direct use by water users. The interactivity of the systems is promoted by the integration of feature services which enable spatial and attribute edits and updates to the geodatabase via the web. Finally, both systems encourage the active involvement of stakeholders and public participation, since customised modules have been created for commenting on the broadcasted outputs.

The case of international water resources management and governance is of particular interest, because it combines physical, technical, environmental, economical and political issues on regional, national, international and multi-cultural scales, and because it requires a multi-disciplinary approach at every level. Thus, the diffusion of available and harmonized information through web-based platforms can facilitate distance dialogue by providing interactively on the Internet spatially distributed data and distance-based cooperative tools.

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