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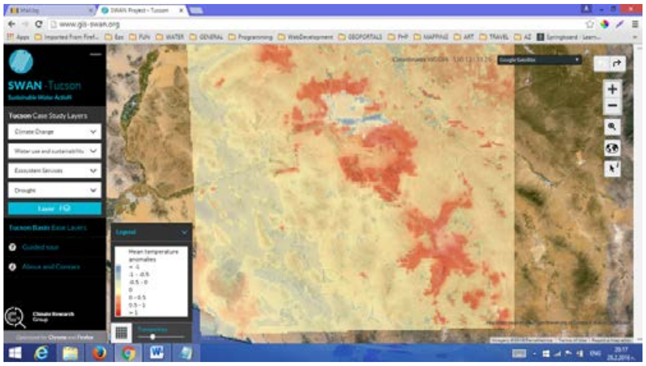

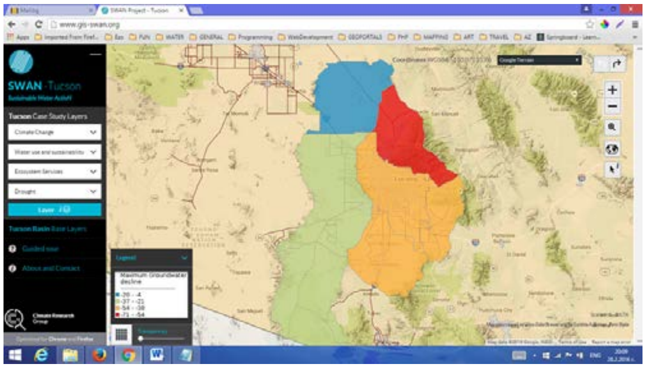

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1. INTRODUCTION

Geospatial information redundancy in the last decades has led to a rapid development of great variety of geospatial approaches, tools and applications used in a range of different fields. Information and Communication Technologies (ICTs) play a critical role in this development and affect business, industry and people’s daily lives trough provision of a virtual space (cyberspace) to undertake many types of activities. The vast amount of generated data through the advanced ICTs as remote sensing - satellite-borne observations and measurements, Global Positioning Systems (GPS), Digital Photogrammetry, internet-based sensors and other ICTs has reflected in growing social impacts and benefits in knowledge, management and decision making processes. The technical advances in hardware, software and data management have been fundamental for geovisualization. The geovisualization combines the strengths of the human creativity and general knowledge with the computational power of present-day computers to explore the knowledge from large geospatial datasets. A driving force for geovisualization progress is the rapid development of internet-based applications and the use of Internet as a medium for dissemination of geospatial data and maps. In general the Web paradigm shifted from passive to intelligent web respectively, influencing the web services and content in order to fit the users’ demands.

A common definition of geovisualization was given in 2001 research agenda of the International Cartographic Association (ICA) Commission on Visualization and Virtual Environments: “Geovisualization integrates approaches from visualization in scientific computing (ViSC), cartography, image analysis, information visualization, exploratory data analysis (EDA), and geographic information systems (GISystems) to provide theory, methods and tools for visual exploration, analysis, synthesis, and presentation of geospatial data” (MacEachren, A., Kraak M., 2001).

The invented in 1990 World Wide Web (WWW), Uniform Resource Locator (URL), Hypertext Transfer Protocol (HTTP), Hyper Text Markup Language (HTML) and the first browser by Tim Berners-Lee, a researcher at CERN, were significant milestones in the development of ITCs. They have changed the role of the computers and respectively the live and work of the people. The World Wide Web is a system of interlinked hypertext documents and programs that can be accessed via Internet primarily by using HTTP. The Web is expanding continuously through wireless networks and mobile web. The new version of WWW, Web 2.0 is read-write web with abundance of user generated content (UGC) and bottom-up information flow.

Another important technology with a rapid progress in the present day society connected with the geovisualization is the Geographical Information System (GIS). GIS is “an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information” (*ESRI, Understanding GIS: The ARC/INFO Method/Redlands)*. GIS represents the real world through data models consisting of multiple layers. Data management and analysis capabilities of GIS turn it into powerful tool for problem solving and decision making.

A fast growing trend in ITCs influencing different aspects of development of software tools and applications connected with geovisualization is cloud computing and more precisely the construction, deployment and delivery of cloud services and environments. The paradigm of cloud computing allows users to provide cloud-based resources, application services, development platforms and virtualization infrastructures. In the context of cloud computing, one server is usually responsible to run multiple applications and a single application is spread across multiple servers (*Zaigham, M., 2013).* The dynamic, virtualized, distributed and multi-tenant nature of the cloud environment has numerous benefits, however it inherits issues of concerns related to the security and privacy of users’ data, and interoperability of services across different clouds. Cloud computing promises substantial on-demand computing and storage capabilities, scalability by design and different levels of services.

2. OVERVIEW

Geodatasets have grown dramatically in size and number posing great challenges to handle with petabytes of heterogeneous environmental and social data. The efficiency of management, integration and data mining in the ocean of information is being improved continuously addressing the increased community requirements and supporting the decision making processes. The great variety of advanced data processing techniques, model simulation and optimization procedures assist in improvement in data quality and accelerate the decision making process.

The study of different aspects of visualization requires a multidisciplinary and multidimensional analysis. Nowadays the development of software and Internet technologies allow everybody to create or modify visual representations and to spread them. The visualization is a complex process consisting of data processing phase (data selection, filtering, annotation, aggregation etc.), a phase of analysis (pattern detection, overlaying analysis, cluster analysis, index or indicators development, statistical or comparative analysis etc.) and finally the phase of visual data representations. In fact the revolutionary innovation in geovisualization has been made by the interactive maps design, which leads to users deeper involvement and expands data sharing processes developing also the collaborative dimension of data visualization. Geovisualization comprises a set of tools and techniques dealing with geospatial data and analysis. In general geovisualization systems collect and access data from multiple sources, which lead to some difficulties in combining and transmitting them into an interoperable system. The choice of the representation methods depends on different factors as visual variables (colors, size etc.), representation scale, choice of spatial data model, number of the objects that have to be visualized, the use of directly measured data etc. Geovisualization research stresses primarily on the geospatial virtual environment, dynamic representations and user interface design.

Open Knowledge and geovisualization

The collaborative effort to share data resources and development experience has been greatly increasing in the recent decades. Mainly two organizations have been coordinating the development of the open specifications - the OpenGIS Consortium Inc. (OGC) (http://www.opengis.org) and the World Wide Web Consortium (W3C) [http://www.w3.org]. In 1999, the Open Geospatial Consortium (OGC) has begun establishment of Web Map Services standards. The OGC comprising hundreds of companies, universities and government agencies participating in the process of developing public standards supporting interoperable solutions for geo-web, location-based services and data flows. Strategic Goals of the OGC includes provision of free available standards, delivery and integration of geospatial content and services and support in creation of innovative applications for geospatial technologies [http://www.opengeospatial.org/]

The open standards approach coupled with open source software allows easier resource and experience sharing resulting in development of great number of customized applications.

The Open-Source Systems have expanded in different directions covering the whole range of software applications and tools development. In the field of RDBMS increasingly popular is the PostgreSQL database, which is an SQL-supporting successor to the Postgres DBMS, which was developed up until 1993 at the University of Berkeley. It is a free, open-source, object-relational DBMS that can support databases with several orders of magnitude and provides powerful search, query, update and management tools.

In 2005, Google released Google Maps, a web mapping application developed on top of dynamic HTML, ECMAScript, and XMLhttpRequests (also known as AJAX). The so-called slippy map grew highly popular because of its simple user interface and good performance, due to prerendered tilesets organized in a quad-tree scheme. The fact that Google opened its application programming interface (API) for third-party developers for free reuse made it quickly highly popular, triggering thousands of Google Maps-derived web mapping applications. Technically, Google Maps is based on quad-tree raster tiles of aerial images, road maps and a geospatial search engine.

OpenLayers – a client-side web mapping framework for integration of various data sources, among them Google Maps, Bing Maps, Yahoo Maps, OGC services, and many others. Today, OpenLayers is one of the most popular web mapping clients, used in both open-source and proprietary web mapping solutions.

3. DATA MANAGEMENT

Data has the value of information in case of correct interpretation and application to appropriate problems. The dramatic increase in availability of geographic reference data results in a rapid development of commercial and open-source software dealing with spatial data storage and analysis. The typical data pre-processing includes data cleaning, data integration and data transformation operations.

The complexity of spatial datasets raises many issues and challenges concerning data integration, design of new applications and services. The primary target of systems dealing with spatial data remains geographical applications. In general spatial data could be divided into two basic types - geometry and geography data types. The geometry data type supports planar, or Euclidean data, while the geography type of data consist of ellipsoidal (round-earth) data, such as latitude and longitude coordinates. Spatial databases tend to be huge and spatial queries need to be supported by adequate spatial indexing. Some solutions already exist – like quadtrees and R-trees. The dimensionality of spatial data – two- or three- dimensional adds more complexity of handling such data (http://icaci.org/research-agenda/geographic-information/).

The available data on various web sites are highly heterogeneous. The input for the datasets used in the visual analytics process could be from numerous data sources and the **heterogeneity** could be in many aspects, such as within data formats, data content, data accuracy, spatial data resolution and time scale. The heterogeneity is attendant to the web data as the data collection process is at numerous levels (municipal, regional, national and international), hence the key requirement for communicating information is **standardization**. Most often representations of data are valid only for a certain place and a certain period, that is why visual characteristics need to be encoded in a standard way including the main cases that can be found.

The issue of **multiresolution** is also of significant importance for geovisualization - each available data set can have a different resolution level and the spatial data needs to be generated at a required resolution level on the fly. The issue is complicated because different type of spatial data requires specific approaches for dealing with multiresolution representations and resolution transformation. The resolution level transformations can be accelerated through specific algorithms and definition of data structures.

Another main issue is **scalability**: different scales of representation can represent different levels of precision of the information. Scaling is applied in many aspects – in scaling of map symbols by symbolizing aggregated data appropriately to support interactive exploration of space and time, in range grading of data values, in data extremes handling (using thresholds, especially relevant for dynamic web-mapping) etc.

Interoperability is also a main issue for geospatial data management. Different packages and applications are written in various languages such as Python, C++, R, FORTRAN and are not **interoperable**, which may lead to repeated developments of similar analytical functions. The interoperability of visualizations allows the user to work with one application and then to use the results in a context of another application, and to be able to connect several different applications through the use of similar or convertible files formats. The issue is still difficult to solve, especially because there is a problem of interoperability of visualization softwares and geospatial data. The standards help the development of interoperable applications and the **standardization** process could guarantee an interoperability in every field.

"Spatial Schema" is the specification of a vector-based geometry data model given in the standard *19107* [http://www.iso.org/iso/catalogue_detail.htm?csnumber=26012] and an object-oriented conceptual model for spatial databases design using the Spatial Schema as geometry model is given in the standard 19109 (called "Rules for Application Schemas") [http://www.iso.org/iso/catalogue_detail.htm?csnumber=39891].

Main driver for data standardization from a European perspective is the **INSPIRE** (*Infrastructure for Spatial Information in Europe*) directive (*Directive 2007/2/EC*) of the European Parliament and of the Council [http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32007L0002]. The goal of INSPIRE is to build an infrastructure for provision of harmonized spatial information across the members of the European Union (EU), supporting European and national environmental policies or activities, which may have an impact on the environment [http://inspire.ec.europa.eu/].

Member states have to provide access to existing geographic data sets and services according to the so-called Implementing Rules. These rules define standards for data specifications, metadata, service architectures and terms and conditions facilitating the creation, discovery, provision and sharing of these spatial data sets. INSPIRE defines also what data themes have to be made available. As a result, not only is each member state required to set up its national spatial data infrastructure, but also many national organisations are involved as a provider of data sets defined by INSPIRE [*Peterson, M.P., 2012*]. Therefore the INSPIRE directive is needed for enabling interoperable access to the spatial data.

Data conversion, transformation, migration, integration and validation are extremely important for processing, storage, security and sharing of the data and respectively for the extraction of the necessary information from the datasets.

Data quality has crucial importance for the development of Web GIS applications. A special part of metadata describes the quality information [*http://icaci.org/research-agenda/metadata-and-sdis/*] by giving details about the data collection process. The data must be consistent with the Information Quality Standards at all levels (national and international).

High-quality and reliable datasets provide opportunities for more reliable and objective analysis and evaluation by the researchers and respectively address better the needs of the community. The loop is closed, as the better is the quality of the data, the more useful and beneficial they could be for the decision making and management purposes. Loss of data quality can occur at many stages: collection, digitization, archiving documentation, manipulation and through the use. The quality should be also considered specifically depending on the purpose of the planned use. Considerations have to include collection methods, periodicity, timeframe, completeness and many other aspects.

The Web has promoted a new approach for representing information deriving from the use of HTML and XML. The approach describe formal data models without depending on a specific tag language and is called “semistructured data management”. The integration of spatial data in a *semistructured data model* is an issue that has been addressed by the OGC through the definition of the geography markup language (GML).

4. THE GEOSPATIAL WEB

In the recent years WebGIS and Distributed GIServices are growing exponentially. WebGIS is a GIS distributed across a computer network to integrate, disseminate, and communicate geographic information on the WWW [*Peng, Tsou,2003.*.]. It provides the end-users with a cost-saving solution to access up-to-date spatial datasets and information [*Horanont et al., 2002; Painho et al., 2001]*.

The web is widely used as a dissemination medium for geodata and maps, and it is used not only for data provision but also for delivering geo-processing functionalities called web services. Data transfer and geovisual analytical functions are provided for the needs of the clients through the web. The progress in the ICTs sector has increased the opportunities for geographic information sharing and real-time maps generation, it also facilitates the dissemination and development of personalized map content as well as frequent updates. The boom in the development of mobile devices has also risen the share of the dynamic web-map content and interactivity. The first web-maps were mainly static. Currently the dynamic interaction within the geospatial web applications has a profound impact on knowledge management and workflows structuring across and within organizations, and on the communication between like-minded individuals in virtual communities.

WebGIS can be distinguished between data services and map services. Data services allow clients to retrieve spatial data from the Internet, and the dataset is immediately accessible to all users through the Web server. Map services are constrained to online use and no data can be retrieved to the local machines. Google Maps, OpenLayers, Yahoo! Maps, MapQuest etc. are examples for web-based online mapping applications. Recent works on Web Engineering have proposed architectures based on mapping services. Mashlight and DashMash, for example, generate applications containing mapping components with geolocation information and offer flexibility for creating geographic applications. The capability of GIS application is determined by the use of the Web server. Popular types of GIS clients are online virtual globes as NASA World Wind, Google Earth, Skyline Globe, MS Bing Maps etc. serving as geobrowsers.

Web services can be broadly classified into two groups based on the protocols used to exchange and access information – REST (*Representational State Transfer*) and SOAP (*Simple Object Access Protocol*) based services. Most web services developed according to the standards established by the OGC supports both groups. Each web service is tied to an XML-based document describing its interface (WSDL - *Web Service Description Document)*, and communicates with clients or other web services through SOAP-based messages. The web services can be considered as an external library that can be incorporated into any existing application through API (*Application Programming Interface*).

The OGC Web Map Service (WMS) allows to overlay map images from Internet and displaying them, while the Web Feature Service (WFS), allows to retrieve and update geospatial data encoded in Geography Markup Language (GML). They provide flexibility for the web-mapping applications.

Regarding web standards, the most important developments of the past years were SVG and Canvas for (vector) graphics, HTML5 for general web content, application development, and interactivity, CSS3 for styling, and recently WebGL for 3-D content.

There are many challenges for the Web GIS applications development as the frequency of data reading/writing, limited capabilities of web-browsers, number of simultaneous users, large volumes transfer and some others.

Visualizing and analyzing large spatiotemporal data in a web-based environment becomes a big challenge for researchers. The most fundamental challenge for Big Data applications is to explore the large volumes of data and extract useful information or knowledge for future actions [*Rajaraman, A., Ullman J., 2011*]. Many of the existing data visualization techniques are limited to display a few thousands items. A solution of the problem was the development of varieties of new approaches dealing with large data sets as exploratory spatial data analysis (ESDA) for geovisualization, data mining techniques, special techniques as dynamic labeling, changes in transparency and shading, animations representing big datasets etc.

Large and complex datasets are generated, for example, by climate models through simulations of climate conditions values over time and space. These spatiotemporal data include dozens of climate variables with different spatial dimensions, different temporal resolutions (from daily to yearly), different scales (from global to regional) and models are run continuously with different combinations of input parameters. Hence, processing of the generated climate data requires web-based environment to tackle with the distributed computational resources and distributed data users. Standalone systems require sufficient computing resources on local machines for large datasets, thus web-based systems address the deficiencies of using local machines. Temporal data abstraction, principal component analysis (PCA) and clustering of large volumes of time-oriented data are some of the methods for visualization of large climate datasets.

Spatial databases and geovisualization platforms for ecosystem services

Ecosystem services (ES) are the benefits that people derive from nature. Human well-being depends on these services, and therefore management of the ecosystems that provide them is a very important issue. Ecosystem services link ecological with sociological data, assess the interactions among them and are used to inform policy and decision-making by standing on the science-policy interface. They can be accessed through simple or more complex models and indicators, which are the basis for map generation (Drakou et al. 2013). There is already a broad range of web tools available that deal with ecosystem services and is either focusing on providing catalogues of ecosystem service assessments, such as the ES Indicator database by the World Resources Institute (WRI) or the IPBES catalogue of assessments.

The development of a "Catalogue of Assessments on Biodiversity and Ecosystem Services" was called for by the meeting which established the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES). The primary intention was to learn lessons from existing and ongoing assessment processes so as to inform the future development of IPBES, and a critical review of assessments to be delivered to the first IPBES Plenary will draw heavily on the catalogue. The tool (http://catalog.ipbes.net/#) comprises map viewer with basic functionalities that shows locations of the existing assessments worldwide. The project is new, thus the structure, functions and use of the tool have not been finalized yet. The Digital Observatory for Protected Areas DOPA (http://dopa.jrc.ec.europa.eu/) is a set of distributed databases combined with open, interoperable web services that provides end-users with means to assess monitor and forecast the state and pressure of protected areas at the global scale. The mapping services used for DOPA could be used as web client as regards to the ES component. Currently only the Carbon Calculator is available online. The Marine Ecosystem Service Valuation Database (http://marineecosystemservices.org/explore) is an online system that provides information on ES valuations of marine ecosystems that have been done globally, but also gives the user the chance to upload data. The map viewer provides information of the regions where such assessments have been done and gives a list of all assessments conducted in the respective region. There is also an option to select ecosystem type and the viewer shows the regions where this type was assessed providing extraction of the previously mentioned list.

The Blue Carbon Portal (http://bluecarbonportal.org/the-new-blue-carbon-homepage-2/who-i-am/#map1) is a geographic overview about global blue carbon activities. The portal brings together the latest knowledge and resources for blue carbon and aims to provide a central and accessible location to keep all parties up to date on new results, upcoming events, and find out whom else is out there that might be tacking similar questions and challenges. The South East Queensland (SEQ) framework (http://www.ecosystemservicesseq.com.au/ ecosystem-reporting-categories.html) is a project developed on an 'agreed' framework for assessing the ES derived from the SEQ region and to incorporate this information into natural resource management, policy and planning.

The Ecosystem Services Partnership (ESP) visualization tool (http://esp-mapping.net/Home/) is designed to serve as a data repository for ecosystem service maps, relevant indicators, models and methods used to primary data generation. It gives the users access to a database of ecosystem service map records and allows them to download and also upload their own ecosystem service maps. Therefore, it is a data and knowledge sharing platform for ecosystem services maps. The tool consists of two major components: 1) the ES Map Documentation Database; and 2) map viewer. The first consists of various fields describing the ES map metadata. The map records are either published online by the system administrators or by the external registered users. The Map viewer contains interface consists of a global map through which the users can navigate and search the database for ecosystem service maps based on different selection criteria. For each returned record, the users can visualize and download the map and the linked to it metadata linked to it (Drakou et al. 2013). The tool has the following main functionalities: 1) Data filtering and selection; 2) map visualization and navigation; 3) map and data upload; 4) Feedback platform. The tool is a platform for information exchange on ecosystem service maps and indicators, from data, models and methodologies used, to the specific purpose these different approaches serve. The target audiences are researchers, students and ecosystem services practitioners. The goal of the tool is to serve as a guide for people who wish to map ecosystem services and allow for an exchange of ideas on methodologies and data used. It also gives the possibility to the users to comment on the available information, which is a way to validate the maps that have already been uploaded and use the tool as a platform that allows for discussions among the ES practitioners.

Web-based GIS tool for water related ecosystem services

Quantification and visualization of spatial research findings, i.e. water related ES, are usually carried out in a desktop geographical information system (GIS). The new technical means allows the setting up of a spatial data infrastructure (SDI) where baseline data, models and results can be shared, used and distributed in a more appropriate manner. The technological concept of web services means to access distributed information via service-oriented architecture (fig. 1). Therefore, the user can acquire the information via specifications of the Open Geospatial Consortium (OGC) where the data are not downloaded on the user's computer. SDIs describe a framework of spatial data, metadata, users and tools that are interactively connected. With reference to the INSPIRE directive the advantages of SDIs are the effective organization and distribution of geodata while the SOA is independent from operating systems, programming language and the programming environment.

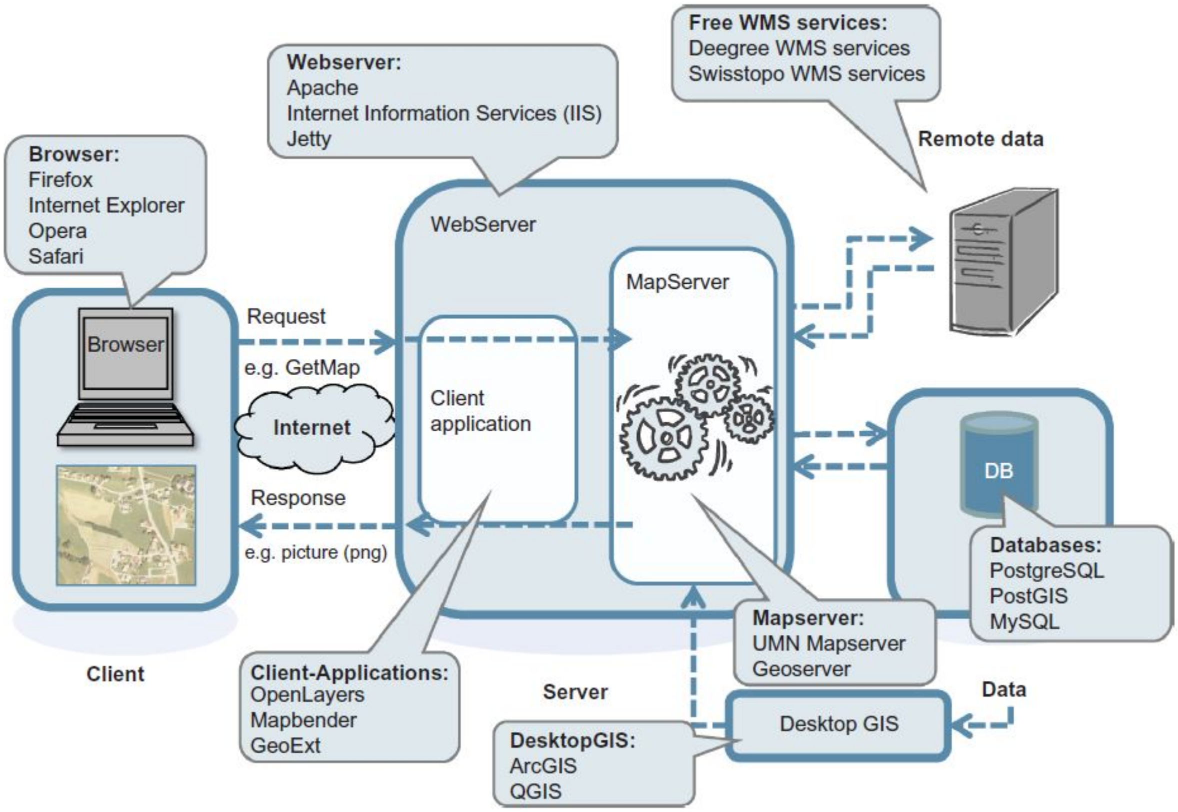

Figure 1. Service oriented architecture for WebGIS (Klug et al. 2012)

An open source-based geoportal for freshwater ecosystem services in the Alps (Klug et al, 2012) provides an appropriate example of the advantages given by this technology. It consists of a HTML website embedding several JavaScript libraries for the spatial components and functionalities. The system consists of three main components – client, server and data (fig. 3). The server is updated using Microsoft Windows Server 20013, PostgreSQL 9.1 extended with

PostGIS 1.5 and Geoserver 2.0.2. It uses JavaScript libraries such as OpenLayers, ExtJS and GeoExt. The user interface of the web portal is subdivided into three vertical frames. The left frame contains the overall project information. The centre frame shows the map containing baseline data sets and the drinking water consumption results to be presented as follows. The right frame is vertically split in a search option, legend of presented layers, available layers (data sets) and the status and copyright area. The tool ensures generation of maps different aspects of water consumption and water supply.

5. GEOVISUALIZATION TOOLS DEVELOPMENT FOR TUCSON BASIN CASE STUDY AREA

SWAN book data-viewer

The spatial data results from the issued by the SWAN partners book "Water Bankruptcy in the Land of Plenty" *Steps Towards a Transatlantic and Transdiscilinary Assessment of Water Scarcity in Southern Arizona*, are presented in a web-based data viewer. The book includes the socio-historic perspectives on water in the American Southwest, narratives of urban growth, water-related ecosystem services, water use and groundwater management and stakeholders' perspectives.

The viewer is designed to disseminate the spatial data results obtained from the authors of the chapters of the book through their research. The tool is a result from the collaborative work between the Spanish and the Bulgarian teams. The web-page is hosted at the server of Seville University, Spain. The web-address is: **http://www.gis-swan.org/**

The tool is developed based only on open source software. It allows users to visualize and interact with the spatial data. The web-based GIS application provides functions necessary to convey environmental and social data to experts and non-experts. The swing panel comprises basic and specific layers, designed to display specific information about Tucson Basin area and its surroundings. The user could switch on the desirable number of layers. Eight options are available for choice of a background base map (Google maps, Open street maps and Stamen maps).

For the basic layers were used processed spatial data for Arizona state from the University of Arizona Library, U.S. Geological Survey and National Atlas of the United States. The group includes more than 30 layers organized in three main subgroups: Water Systems, Land Cover System and Territory System.

The specific layers groups include the data from the researchers, respectively water metabolism and sustainability research data of Violeta Cabello (water use layers, administrative layers etc.), water-related ecosystem services (ES) data from Kremena Boyanova (land use data, ecosystem services layers etc.), ES data from Rositsa Yaneva, ground water and management data from Natlia Limones, climate data from the Climate monitoring tool developed by the Spanish team and some others. Each chapter of the book is connected by link to the respective data layers showing researchers' results.

The *Graphical User Interface (GUI)* is developed by José María Amuedo under the supervision of Dr. Juan Mariano Camarillo. *GeoServer* open source software is used for the web-representation of the layers through *Web Map Services (WMS)*. The basic *Map display tools* are included in a navigation toolbar, which enables the users to view area of choice using tools such as identification, Zoom In, Zoom Out, Zoom to scale etc.

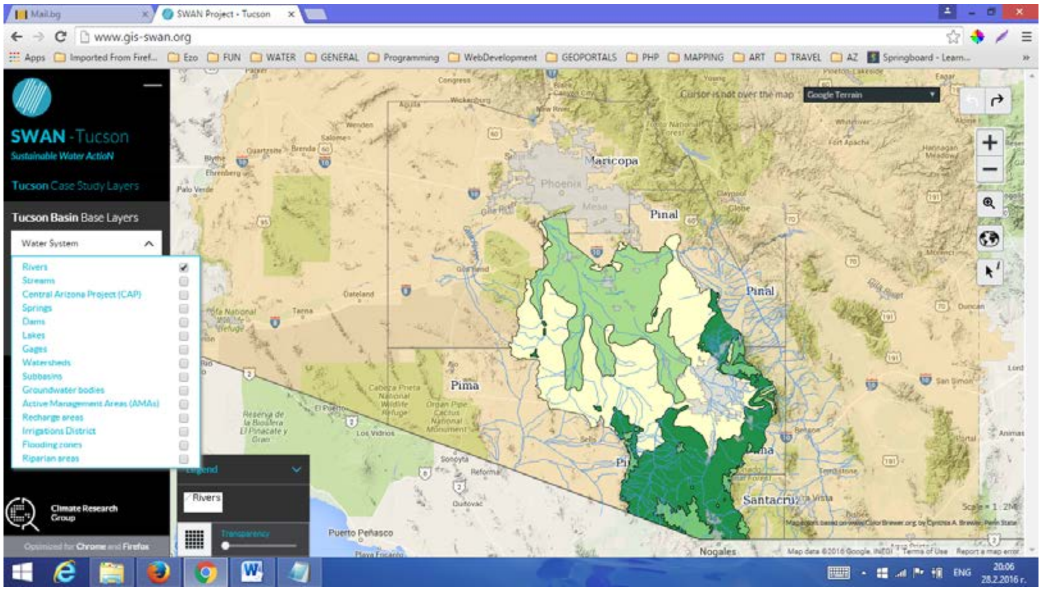

Figure 2. Graphical User Interface of the SWAN-book data viewer - snapshot of the website with several basic layers

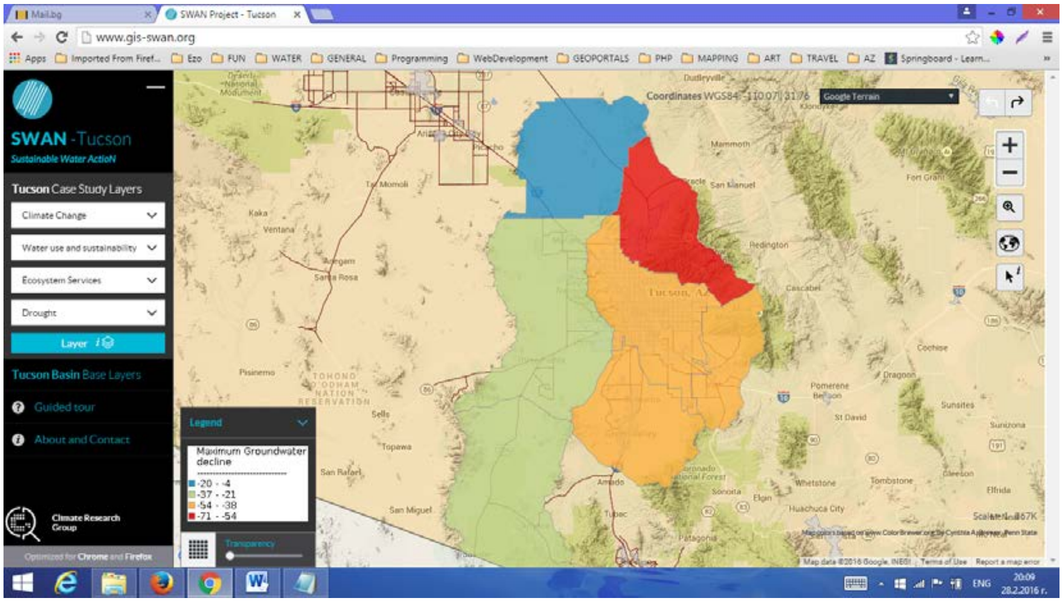

Figure 3. SWAN-book data viewer showing research layer showing Maximum water decline

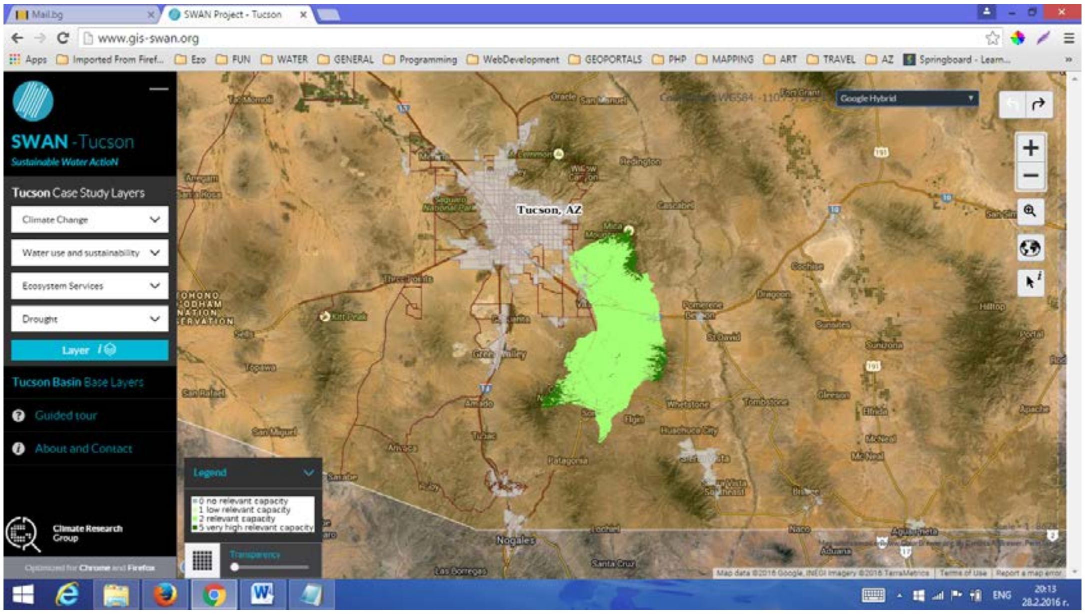

Figure 4. SWAN-book data viewer showing research layer “Fresh water providing ES Supply capacities SWAN”

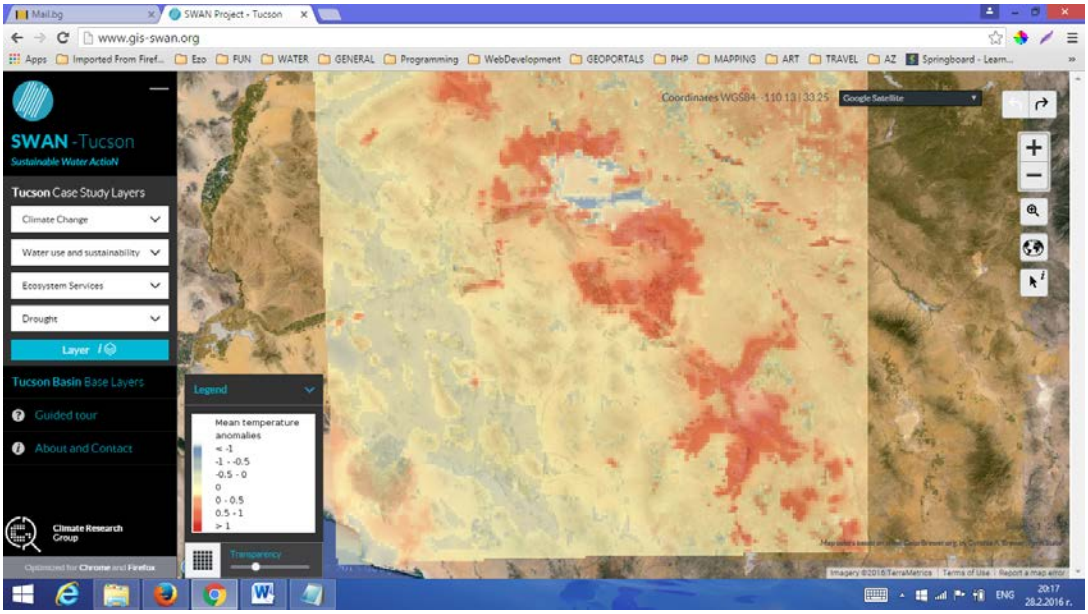

Figure 5. SWAN-book data viewer showing research layer “Mean temperature anomalies”

The application could serve as a useful communication tool between the stakeholders and the researchers through exchange of valuable information about the water resources in Tucson Basin Active Management Area and also to assist in the complex process of the sustainable water management. The main goal is wider dissemination of the research results.

6. CONTRIBUTION OF GEOVISUALIZATION TO VIRTUAL COLLABORATION

The creation of an interactive visual web environment for the need of different users requires complex approaches. Geovisual tools have the potential to provide convenient methods to access the necessary data, to discover the relationships between various parameters, and to communicate the results across the end-users. The user interaction with the visual interface is where the insight happens, hence they are useful for both – researchers and stakeholders. Geovisualization has been proved to be an efficient method for understanding of complex geospatial data. The potential benefits of geovisualization are in many aspects: interaction and communication aspects (dissemination; usability, collaboration and sharing, networking), cognitive aspect (finding patterns, gaining new insight, stimulating visual thinking, spatial awareness), practical aspects (application in the decision making process) etc. The joint display of the results of the researchers from different fields of study gives the opportunity to compare and discover unique trends and aspects through overlaying particular datasets.

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