

Concept of a Cartographic Platform for Spatial Data

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Be received 17.11.2022

Abstract. *Modern scientific research increasingly relies on geographic information systems and spatial data. However, geospatial data created by researchers often remains locked within institutional silos — it is not properly stored, is not subject to sharing, and is inaccessible to other researchers or students. This problem is particularly acute in developing countries, including Georgia, where the culture of systematizing and sharing spatial data is still in the process of formation.*

Proceeding from this problem, within the framework of this paper we set out to create a cartographic platform for spatial data based on open-source software, taking into account the SDIlight approach of the University of Twente.

Reproducibility is one of the most important aspects of science — a function that allows researchers to repeatedly use and verify data and methods. Spatial data infrastructure forms the basis for sharing research results and spatial data, enabling researchers, organizations, and decision-makers to effectively collect, process, analyze, and disseminate geospatial information using common standards and protocols.

Keywords: *open-source platforms, spatial data infrastructure, stakeholders, spatial analysis, PostGIS.*

1. Introduction

Spatial data occupies an important place in modern research. Creating new data is associated with expensive technologies and, as a rule, requires a great deal of time and intellectual resources. Geospatial data is widely used in scientific research, but geospatial data created by researchers is rarely accessible and usable — for example, for educational purposes or for research following the completion of a project (Köbben, Rolf and Foerster 2010). Proceeding from this problem, the objective of the research is to define an SDI model for Georgian academic institutions, aimed at expanding the accessibility and usability of existing data already created by other researchers.

Within the scope of a desk study, we examined best practices in the use of SDI at several leading higher education institutions in Europe, on the basis of which we defined an academic SDI for research and teaching.

The research aims to define an optimal model of spatial data infrastructure for Georgian academic institutions and, on the basis of this model, to create a geoportal for an academic spatial data infrastructure for scientific and educational purposes.

The optimal academic SDI model that we developed for Georgian academic institutions can also be viewed as an optimization of GIS technology, since it addresses tasks that GIS alone cannot — specifically, the systematization of data, sharing, and the organization of search systems. It facilitates the repeated use of data created by researchers and saves time and financial resources through the joint use of data.

In modern conditions, scientific research is closely linked to the use of geographic information systems (GIS) and the accumulation of various types of spatial resources, such as raster, vector, and attribute data. This process is particularly important in local-level research, where primary spatial data on geographic objects is collected and information is subsequently produced on the basis of that data. For systematization and the organization of search processes, GIS tools alone are insufficient for the acquisition and sharing of geographic data — the creation of a dedicated local spatial data infrastructure is essential (Nebert 2008). Moreover, a special approach is required to create a system oriented toward supporting scientific-research and educational tasks with information (Coetzee et al. 2017).

The era of GIS development is considered to span the early 1960s to the mid-1990s of the last century. This was the period in which digital technologies emerged in cartography, and large volumes of digital spatial data were accumulated along with the creation of geoinformation systems for various purposes (Nebert 2008).

Mass use of this data proved impossible due to a number of problems:

- concentration of information within certain organizations and inaccessibility to external users;
- absence of mechanisms for searching for and gathering necessary information;
- absence of standards for spatial data, leading to their incompatibility;
- restrictions on the use of information (classification/secretcy).

These problems lead to significant losses of time spent searching for information that is, to some extent, essential to making important decisions. They also cause duplication of work involved in creating spatial data. In the 1990s, the necessity of overcoming these existing problems was recognized, which led to the idea of creating a spatial data infrastructure and to the beginning of a new era in geoinformatics.

It should be taken into account that information is a costly resource. For this reason, appropriate information and the resources needed to make full use of it may not always be readily accessible. In particular, in developing countries, many national, regional, and international programs and projects are directed toward improving the availability of existing spatial data, facilitating its repeated use, and, through additional investment, ensuring the accumulation of spatial data and the management of results within an ever-growing pool of spatial information (Nebert 2008).

The term “spatial data infrastructure” was proposed by the United States National Science Foundation in 1993. The key word, “infrastructure,” very successfully conveys the essence of the idea that geospatial data should become as accessible an infrastructure to everyone as, for example, transportation infrastructure. The term “spatial data infrastructure” is often used to denote a set of technologies, policies, and standards that facilitates the existence of and access to spatial data. It provides the basis for the discovery, evaluation, and use of spatial data by users and providers.

SDI is an evolving concept for simplifying and coordinating the exchange of geospatial data and services among various levels of stakeholders in society.

The purpose, role, scope, and potential stakeholders of academic SDI are described on the basis of the formal SDI model developed under the standards of the SDI Commission and the International Cartographic Association (ICA). The results will contribute to an understanding of the current state of SDI implementation in higher education institutions and research institutes, an analysis of what distinguishes academic SDI, and identification of who may be the users of research and educational SDI.

A national-level SDI simplifies the exchange of geospatial data accessible to everyone within a country. Similarly, regional and territorial SDI enable the exchange of information across different administrative levels. In this regard, the situation differs in the field of education and science. Like books and journals, geospatial data is widely used in research, but geospatial data created by researchers is rarely transferred to others or properly stored, and is therefore rarely registered in specialized data catalogues.

The introduction of SDI and associated geospatial data catalogues in universities and research institutes improves access to geospatial data and its prospects for repeated use (Coetzee et al. 2017). This opens up the possibility of using existing data in new research or in follow-up studies. At the same time, research results become accessible to sponsors and the public. Importantly, scientists and researchers no longer need to spend time and resources acquiring the same data and building databases repeatedly.

2. Research Methodology

Given the relevance of the problem, the objective of the research was set as defining an optimal model of spatial data infrastructure for Georgian academic institutions and, on the basis of this model, creating a geoportal for an academic spatial data infrastructure (ASDI) for scientific and educational purposes.

To achieve this objective, the following research stages were defined: (1) on the basis of a desk study, we examined the experience and best practices of leading international higher education institutions. (2) We defined an optimal model of spatial data infrastructure for Georgian academic institutions and, on the basis of this model, created a geoportal for an academic spatial data infrastructure for scientific and educational purposes.

2.1 Concept of the SDI Model

The Commission on SDI and Standards of the International Cartographic Association (ICA) developed a concept for the SDI model (Coetzee et al. 2017). The model describes SDI as represented in the Reference Model of Open Distributed Processing (RM-ODP) (ISO 1998). This model describes six stakeholders of SDI (Table 1).

Table 1. SDI Stakeholders

Stakeholder	Description
Policy maker	Defines SDI policy and policy for all stakeholders
Producer	Producer of SDI data and services
Provider	Ensures delivery of data and services to all SDI users
Broker	Connects users and producers and facilitates agreements between them
Value-added reseller (VAR)	Adds certain functions to created products or groups of products and makes them available as new products
End user	Uses the SDI according to its intended purpose

It can be applied in relation to many different SDIs.

2.2 SDIlight as an Optimal Model

One of the goals of the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente is to build capacity and institutional development in developing countries. The geoinformatics program focuses on two principles: the first concerns the purposeful creation of spatial data and its use in computer systems; the second concerns the methodology for building computer systems and the architecture design of SDI nodes. The term “spatial data infrastructure” (SDI) usually refers to large and complex systems, but its principles can also be applied through simple and cost-effective means. This approach is called SDIlight, and it attracts particular interest among ITC students. At ITC, systems and software modules are built on the basis of open-source components. Open standards of the Open Geospatial Consortium are used to achieve interoperability. The SDIlight approach is effectively applied in the Geoinformatics Master's course. A key part of this course is the development of programs for the study of a specific case, within which students apply their knowledge to a “real-world” project, with particular attention given to the application of geoinformation engineering experience. The effectiveness of applying the SDIlight concept is assessed during the teaching of the geoinformatics master's course, and the methodology is applied more broadly as well (Köbben, Rolf and Foerster 2010).

2.3 Design of an SDI Node Using an Example of Open-Source Software

Within the framework of a desk study, an analysis of demand for SDI in universities and research institutes allowed us to develop an optimal SDI model. We settled on the *SDIlight* approach, which involves applying SDI principles through simple and cost-effective means. The software was selected in accordance with this approach.

The diagram presents an SDI node that enables the use of all functions of an academic SDI. It is based on free software:

- MapServer
- PostgreSQL
- OpenLayers

Data is stored on a PostgreSQL database server, and client access to this data is provided by WMS map servers (Figure 1).

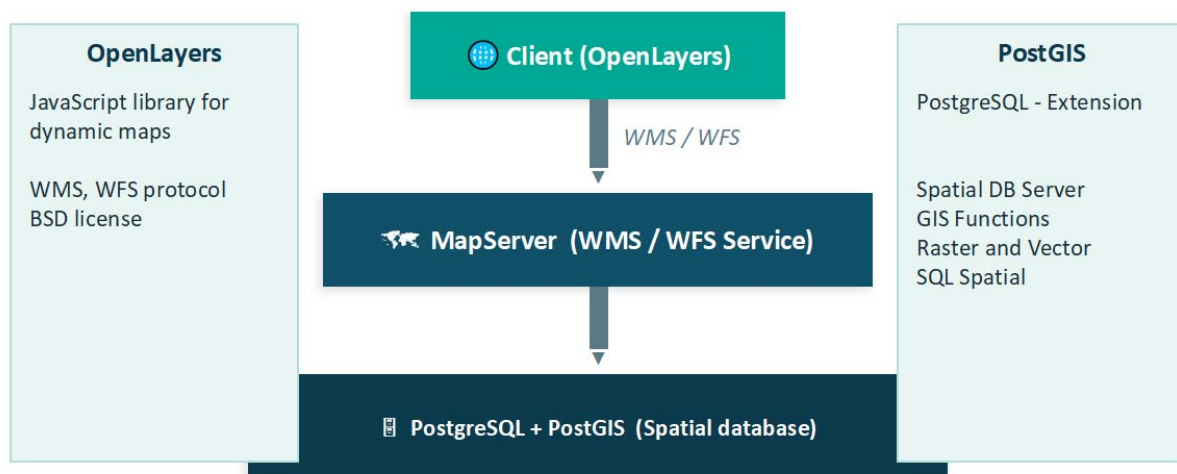


Figure 1. Structure of an SDI node according to the SDIlight approach.

MapServer is a popular open-source project aimed at rendering dynamic spatial maps on the internet. Some of its key features include:

- support for rendering hundreds of raster, vector, and database formats
- the ability to operate across various operating system environments (Windows, Linux, Mac OS X, and others)
- support for popular programming languages and software environments (PHP, Python, Perl, Ruby, Java, .NET)
- operational forecasts
- a wide range of ready-to-use applications with open source code

A map server represents a specialized type of web server. Like a web server, a request is sent to the server, is analyzed, and a response is issued. The key difference between a map server and a standard web server is as follows:

- the response is not a file (.HTML, .ZIP, .MP3, etc.), but rather geographic data.
- the request is more specific than `http://server/file.extension`

Structured protocols are used to request discrete geographic data from the map server (Figure 2). These protocols are: the Web Map Service (WMS) and the Web Feature Service (WFS) (Natsvlishvili 2015).

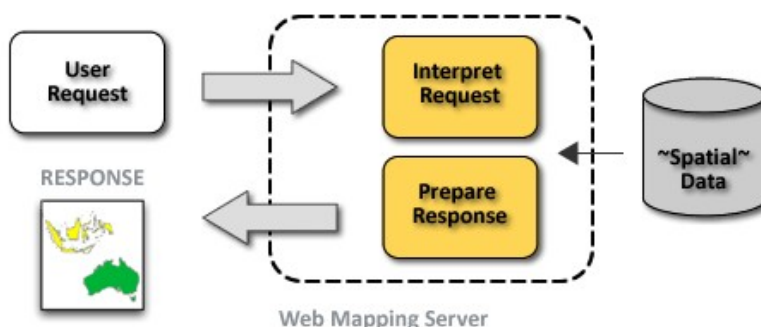


Figure 2. Typical cycle of requesting data from a map server

MapServer's purpose is to render dynamic maps for internet users. The map server functions as a CGI program that runs passively on a web server. When a request is sent to the map server, it uses the information passed via the request URL together with a “map file” (mapfile) to generate the graphical representation of the requested map. Referenced maps, images for legends, and scale bars can be requested and passed as CGI variables (MapServer Team 2023).

An alternative to MapServer is GeoServer, which is likewise a popular open-source map server project (GeoServer team 2023).

PostgreSQL, a database management system, was derived from the POSTGRES package, which was written at the University of California, Berkeley. Today, PostgreSQL is the most modern and accessible open-source database available.

PostGIS is an extension to the PostgreSQL server that turns a PostgreSQL server into a spatial database server for geographic information systems (GIS).

PostgreSQL is a database system capable of operating in resource-constrained environments. Its default configuration is very conservative, so as to fit a variety of environments. Compared to non-spatial databases, geospatial databases require larger records, making it necessary to change the default configuration — something easily achieved by modifying parameters in the configuration file.

OpenLayers makes it possible to easily embed a dynamic map on any web page. It can render map fragments from any source. OpenLayers is a completely free JavaScript library with open source code under the BSD license (also known as the Clear BSD license).

OpenLayers is a JavaScript library for rendering cartographic data in modern internet browsers, without dependence on a server. OpenLayers enables the creation of multifunctional web applications through a JavaScript API, similar to the Google Maps API and MSN Virtual Earth, with one important difference: OpenLayers is free software.

In addition, OpenLayers provides access to geographic data through the standards and protocols of the Open Geospatial Consortium (OGC 2023) — the Web Mapping Service (WMS) and the Web Feature Service (WFS).

3. Geoportal of the Academic Spatial Data Infrastructure

On the basis of a detailed study and analysis of the described technologies, a working geoportal was created, available at: <http://geoportal.levan.link>. The geoportal represents a demonstration version, where the results of three independent studies carried out within the framework of this paper can be viewed in the form of interactive maps (Figures 3 and 4).

Academic SDI

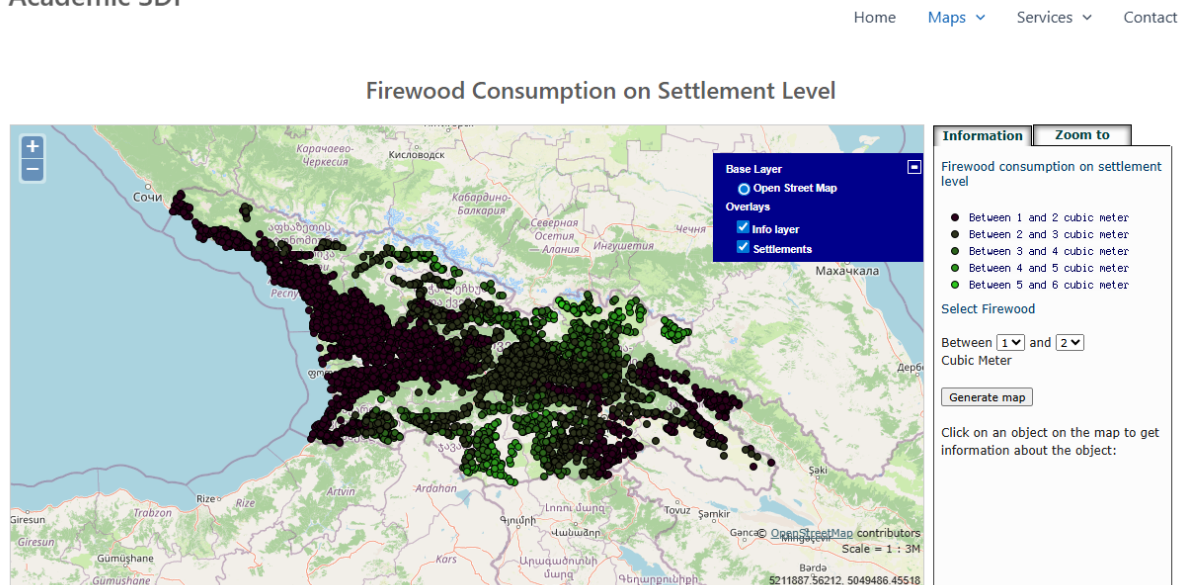


Figure 3. Quantity of firewood required for heating for populated localities in Georgia

Academic SDI

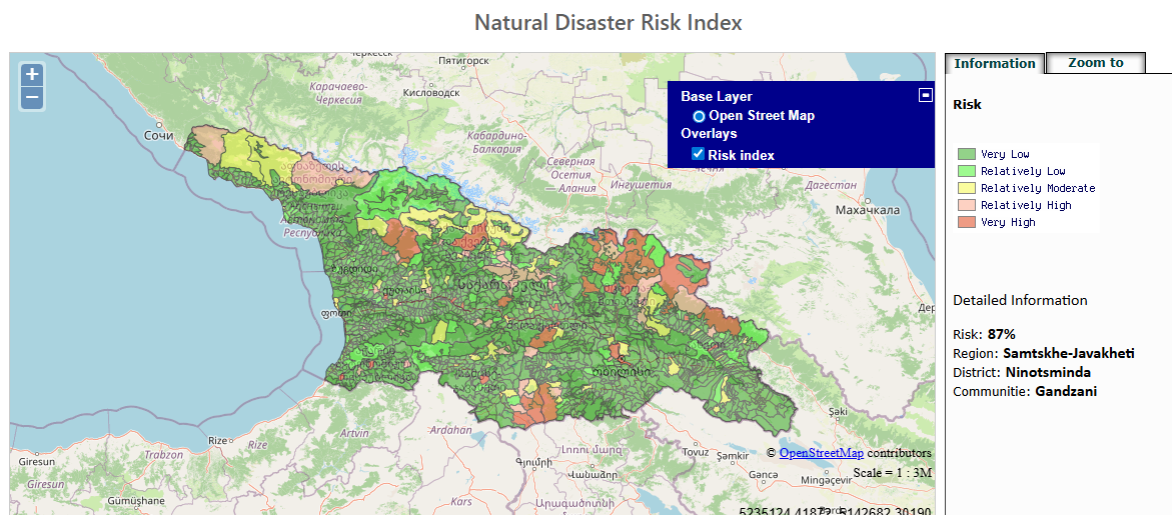
[Home](#) [Maps](#) [Services](#) [Contact](#)


Figure 4. Natural disaster risk index by community in Georgia

The portal enables the downloading and sharing of spatial data. Instructions for using the WMS and WFS protocols are provided, which also allow for requesting maps and data. At this stage, the geoportal is already able to meet the requirements of data availability, systematization, and sharing, and it represents a powerful platform for the visualization and analysis of spatial data. It can also become a subject of study in its own right. Students and researchers will be able to perform PostGIS analysis on spatial data, create interactive maps on various themes, and build software modules for data manipulation, analysis, and statistical processing.

4. Results and Discussion

This paper discusses the methodology for creating an academic spatial data infrastructure (ASDI), which is implemented in line with the SDILight approach and is based on free, open-source software.

It is shown that ASDI promotes the growth of education and scientific potential and serves not only as a source of data for teaching and scientific research, but can also be used as a learning platform for students who need to master the principles of implementing and managing SDI.

An optimal ASDI model was proposed for Georgian universities and research institutes, using specific software. On the basis of this model, an important component of ASDI was created — the geoportal: <http://geoportal.levan.link>, which is entirely based on open-source software. The PostgreSQL/PostGIS server serves the storage and analytical processing of spatial data; MapServer serves the distribution of data via the WMS and WFS standards; OpenLayers provides the interactive web-cartographic interface. The portal enables data downloading, WMS/WFS subscription, and interactive analysis.

The optimal ASDI model that we defined can likewise be viewed as a GIS optimization, since it addresses tasks that cannot be solved within the scope of GIS alone — specifically, data systematization, the organization of search processes, and the acquisition and sharing of geographic data. This will help improve data quality and increase the efficiency of geospatial data management. ASDI can also play a significant role in the development of new applications and services that will assist academic staff in conducting research.

5. Conclusions and Recommendations

The core problem addressed by this research is that Georgian academic institutions lack an optimal SDI model and practical tool that would ensure the systematization and sharing of scientific spatial data. In line with the research hypothesis, the SDIlight approach — a simple and accessible system based on open-source software — can serve as an effective solution to this problem.

Academic SDI can be used as a common platform for data exchange in the form of a geoportal for geospatial data, which researchers can use for sharing, searching, and analyzing data. The introduction of ASDI and associated geospatial data catalogues in universities and research institutes will improve access to geospatial data and the prospects for its repeated use. This opens up the possibility of planning and implementing new research based on existing data and/or expanding existing research. At the same time, research results will become accessible to the broader public. Importantly, scientists and researchers will no longer need to spend time and resources acquiring the same data and building databases repeatedly.

In the case of academic SDI, there is an opportunity to create a group of experts who will manage and develop academic SDI, train representatives of various fields in the use of GIS, thereby advancing cartographic practice and raising public awareness of the importance of geographic information.

A significant obstacle to the realization of academic SDI is the shortage of sustainable funding, hardware, and personnel. A second serious obstacle is the attitude of decision-makers toward the importance of information itself and its sharing. Many organizations lack a policy for managing data obtained as a result of research (Coetzee et al. 2017).

The significance of ASDI can be assessed in two ways: first, by describing the importance of geospatial information for research and education; second, by evaluating the time and financial resources saved through the joint use of data. At the same time, academic SDI can be used as an important teaching platform.

Information on stakeholders and their roles, on the challenges, and on success factors in the implementation of ASDI will contribute to the development of the latest advances in the realization of academic SDI. It provides initial indications of key stakeholders and how they might be engaged at a university or research institute for the implementation of ASDI. Going forward, it will be

necessary to describe academic SDI in greater detail — for example, how it should be applied and implemented.

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