GIS Application for Forest Territories Providing Water Ecosystem Services

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Abstract: - Protecting forests and maintaining their water conservation function has proven to be the most effective approach to generating and maintaining water quantity from the source to the end user. The water conservation and water regulating properties of forest ecosystems that are inherent in forested areas are an undervalued resource at the current stage. To turn this property into a source of income, it needs to be institutionalized as a production function of forest owners. This also defines the main aim of this research, namely to design and implement a system for mapping the territorial distribution and characteristics of sanitary protection zones in Bulgaria, which will help assess the condition and determine the value of ecosystems and ecosystem services. In this regard, this paper presents the approaches used to integrate and design the spatial data of the sanitary protection zones and the database of the forests in Bulgaria in a repository and the system created to visualize these data through different approaches.

Key-Words: - ecosystem service, forest, GIS, Sanitary Protection Zones, water

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1 Introduction

In Bulgaria, the forests are divided into two main groups depending on their purpose: forests with economic importance and forests with a special purpose. The protected forests are a subgroup of forests with special purposes where the forests with water protection functions belong, [1]. The sanitary protection zones (SPZs) around water sources and drinking and domestic water supply facilities are defined, [2], and the conditions and procedures for their study, design, approval, and exploitation are established by the regulation of the Ministry of Environment and Water, the Ministry of Health and the Ministry of Regional Development and Public Works.

The sanitary protection zones consist of three belts according to the adaptive methodology. The inner belt (SPZ-I) includes the territory around the water source which is highly secure and strictly guarded against human activities that may damage the water used. The middle belt (SPZ-II) protects the water source from pollution by chemical, biological, and rapidly decaying substances and activities leading to the reduction or degradation of the quality of the water resources. The outer belt (SPZ-III) includes additional protection of the water source against pollution from slowly degrading and difficult-to-degrade substances.

The forests in Bulgaria and their water protection function in particular are an important part of valuing the water ecosystem service which provides economic value. According to [3], data availability for ecosystem service valuation stands out as one of the main problems because different sources are used for data transfer, such as regional, national, and global statistics.

Our research is related to the water ecosystem service which is provided by forest ecosystems and is one of the 9 paid benefits of forest areas for which users are intended to make payments.

To determine the value of the water ecosystem service, it is necessary to determine the economic value of the productive forest capital. This necessitates the difficult task of studying the territorial distribution and characteristics of the forest areas falling within the scope of SPZs in Bulgaria.

The diversity of data sources and the amount of data to be processed complicate the process of assessing water ecosystem services that are provided by forests. Therefore, it is of particular importance to be able to summarize, visualize and appropriately filter these data to be able to make the necessary decisions.

Therefore, the main objective of the paper is to integrate spatial data on sanitary protection zones and a database on forests in Bulgaria into a repository and to design and create a GIS application that supports the visualization and analysis of these data using different views. To achieve this goal, the following research problems that require a solution have been defined:

- to propose a method for data processing and data aggregation into a repository;
- to propose a GIS architecture for data processing and visualization;
- to implement an experimental prototype based on the proposed data processing method and architecture to validate them.

The paper has been structured as follows. In Section 2 similar works have been discussed. In Section 3, a method for processing spatial data on the sanitary protection zones and a database of forests in Bulgaria has been considered. Section 4 describes the architecture of the WEB GIS application. The main results and data visualization have been provided in Section 4 and Section 5 is the conclusion.

2 Related Works

Ecosystem services are the benefits that people receive from nature, and therefore valuing these services is an important challenge. Therefore, various studies have been conducted that present and discuss a regional ecosystem service assessment and have created their ecosystem map, such as a case study from Romania, [4].

Our research focused on studies that propose the use of a Geographic Information System (GIS) to map territories that are involved in ecosystem service assessment.GIS is used for visualizing, managing, creating, and analyzing geographic data, [5]. Thus, that application will help us to see the linkage and identify patterns in new ways. For example, a web-based GIS/spatial visualization tool provides the ability to view the data in an online map and visually explore the data in a web browser without the need for additional software, [6]. Moreover, in another study, the GIS application adopts a raster format to offer a simple data structure and has high spatial variability representation for easy and efficient overlay analysis, and unified grid cells for several attributes, [7].

The different GIS-based tools help to analyze some priority ecosystem services, [8]. For example, in [9], the authors have created a spatial model, based on GISs, capable of quantifying the potential amount of woody biomass from the forest sector. Even a public participation GIS is used to assess the cultural ecosystem services based on geo-located, passively crowdsourced data from social media through a large amount of available data, [10].

An interesting approach in the use of GIS is the Multi-Criteria Decision Analysis developed to determine forest areas for soil protection function based on erosion risk factors, [11]. The GIS method with an assessment of stakeholders' perceptions is used to measure environmental change, while still considering spatial variation, [12].

A GIS-based approach was designed to collect data, perform spatial analysis, and map the economic values of ecosystem services which is implemented for three key steps of spatial valuation - agricultural products, forest products, and tourism services, [13].

On the other hand, the heterogeneity of data that is being used for service assessment is also challenging. Consequently, the following research proposes a method for applying the standards of interoperability using data provenance between the processing steps in each transition to ensure cohesive workflows across models and platforms, [14].

3 Data Processing

A method is proposed to process spatial data for the SPZs and a database of forests in Bulgaria. The spatial data for the SPZs are provided as three ESRI shape files for each of the three categories. The second data are Excel tables that contain information about the regions, districts, forest groups, year class, SPZs, area, etc. The method contains two main stages as shown in Fig. 1.

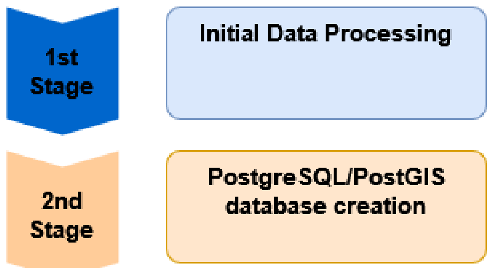

Fig. 1: Data Processing

The first stage is implemented in two steps: the initial processing of the source data and the database design on forests in the SPZs.

In the initial processing of the source data, topological processing of the spatial data for the SPZs was performed. Overlaps were found both between individual layers and between polygons included in each layer. The topological rules "Must Not Overlap with" to detect overlaps between layers and "Must Not Overlap" to detect overlaps between polygons within a layer were used. The following algorithm was applied to remove the detected overlaps:

1) In an ArcGIS environment, territories from SPZ-II and SPZ-III that fell within SPZ-I were sequentially removed; and subsequently, territories from SPZ-III that fell within SPZ-II were removed.
2) Overlaps within each layer were removed.
3) Three generalized layers were created for the individual zone categories.
4) Sections were created between the generalized layers for the SPZs as well as a spatial layer including the boundaries of the municipalities in the country.

The database of forests in the SPZ was created and the following algorithm was used:

1) The cross sections between the national forest layer and the layers obtained as a result of points 3 and 4 of the proposed algorithm using the INTERSECT procedure were created. The execution of the INTERSECT procedure with small objects usually produces parasitic cross sections (SLIVER POLYGONS) - these are polygons with minimal areas and most often have the appearance of long linear objects. The resulting layers were considered based on the Area/Perimeter ratio as a criterion for the removal of such polygons.
   Empirically, for the present data it was found that when the Area/Perimeter ratio is less than 0.3, polygons are subject to removal. Subsequently, polygons with an area of less than 100 sq. m from the dSOZ2_mun_DLESO and dSOZ3_mun_DLESO layers were also excluded from further analyses. Polygons from dSOZ1_mun_DLESO (SPZ-I) were retained regardless of the cross-sectional area due to the fact that there were polygons with an area of less than 10 sq. m in the source database.
2) Selection of database records containing information on the taxonomic characteristics of sub-plots (or parts of sub-plots) falling into the three SPZ categories. These data according to the structure of the forest database are contained in the WOODTYPE table. Three tables were created corresponding to the three SPZ categories obtained from the general forest database and the national parks.
3) The required data contained in a table obtained from the common forest database were added to the six tables.

The second stage of Data Processing is creating a database in a PostgreSQL/PostGIS environment. The database includes source (base) spatial layers and data in the form of three tables that contain the boundaries of the sanitary protection zones for belt1, 2, and 3. The tables have an identical structure and contain the following fields: service identifier, site identifier according to the Ministry of Environment and Water of Bulgaria (MoEW) database, permit number according to the MoEW database, site name according to the MoEW database, Latin name according to the MoEW database, belt, which contains the numeric value 1, 2 or 3 depending on the relevant belt, total stock in cubic meters of woody vegetation present on the site, weighted average increment of the woody species present on the site, site perimeter in linear meters, site area in square meters and a service field.

Three tables were created with information at the subdivision level and by tree species, i.e. the three belts contain attribute type data for the forests in the respective sites. These tables include calculations in terms of average growth, stock, forest groups, etc. Each table has a correlation to the spatial data type table (polygons) for the boundaries of the sanitary protection zones for the respective belt.

The additional tables contained in the DB have type spatial data (polygons) and content as follows:

- x_dgp – boundaries of state forest enterprises.
- x_dgs - boundaries of the State Forests/LFS.
- x_municipalities - boundaries of planning regions.
- x_nuts2 - boundaries of planning regions.
- x_regions - borders of districts.
- x_rfb - boundaries of regional forestry directorates.

The SQL queries are created to reference the materialized views and the data is returned directly like from a table. In order to obtain summary information from the above-mentioned tables, similar SQL queries are generated which include the following fields: 'Identifier', 'Permit', 'Name', 'Tree_species', 'Age', 'Age_class', 'Forest_group', 'Bonite', 'Completeness', 'Area_ha', 'Stock_cube_m', 'District', 'Average_growth', 'Municipality'.

Three MATERIALIZED VIEWS were created as an extract from the respective SPZ boundary tables and information on: geometry, "Identifier", "Permit", "Name", "Total_stock_cubic_m", "Area_ha" and "Average_growth" was obtained using similar SQL queries. The resulting MATERIALIZED VIEWS were converted to tables with the same fields, which were then published to a GeoServer environment for subsequent use in a MapStore environment.

3 Design GIS Application

Open Source software products, compatible with Open Geospatial Consortium (OGC) standards for geospatial information interoperability were used to create the web GIS application.

Fig. 2 shows the architecture of the designed web GIS application. Three main layers have been implemented: Database Layer, Server Layer, and Presentation Layer. PostgreSQL has been used as the database management system, along with its spatial data extension PostGIS. The source databases used were spatial data on sanitary protection zones for each of the three belts and the Bulgarian forest database as of December 2019.

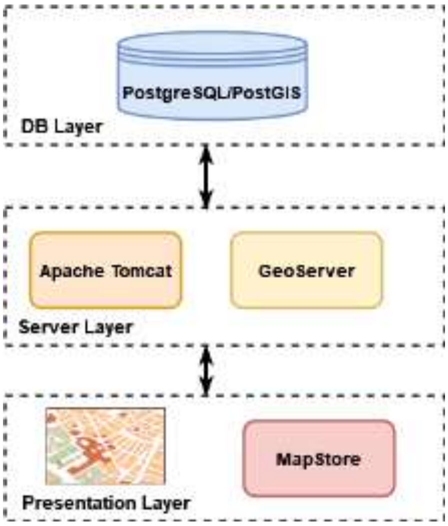

Fig. 2: GIS Application Architecture

The Server Layer contains two servers – GeoServer and Apache Tomcat. The last one works with the forest database and was used for data filtering of the regions, districts, forest groups, year class, SPZs, and area. Geoserver was used to publish the spatial data in a web environment and the MapStore application was used as the end-user interface which is in Presentation Layer. The two software applications, GeoServer and MapStore, are products of the Italian company GeoSolutions.

4 Data Visualization

To visualize the data a Dashboard was created in MapStore to provide a set of information suitably collected to show aggregated data in one view. Geospatial data are displayed on a map along with different widgets, such as tables, charts, and others, which are used to show different kinds of information and details relating to a specific context (Fig. 3).

Fig. 3: GIS application home screen with all filters and statistics

to The system allows users to interact with published dashboards by editing, adding, arranging, resizing, or deleting the widgets inside a dashboard.

The system provides a function that helps users to select which type of widget they want. The process of working with widgets is almost the same for the supported five widget types: chart, text, table, counter, and map (Fig. 4). The process includes the following main three steps: selecting a vector layer, configuring data and saving and adding to the dashboard.

Fig. 4: Widgets in the GIS application

For example, the user can use the chart widget to show and aggregate data, having the option to choose what type of chart they want to use for visualisation – pie, line, or bar charts.

The new interactive map on the dashboard adds more than one map with the ability to connect other widgets to them. After saving the first map, the legend widget will be added to the list. The Legend Widget will show a legend related to the connected map.

5 Results and Discussion

The implemented GIS system fulfills its intended purpose, is user-friendly, and integrates the data from sources to represent the water ecosystem service in Bulgaria. Fig. 5 shows a screenshot of the system when filtering data for a specific SPZ with ID 7245, which is visualized on the map, calculating and displaying the average values of age, health, completeness, growth, total area, and total forest stocks.

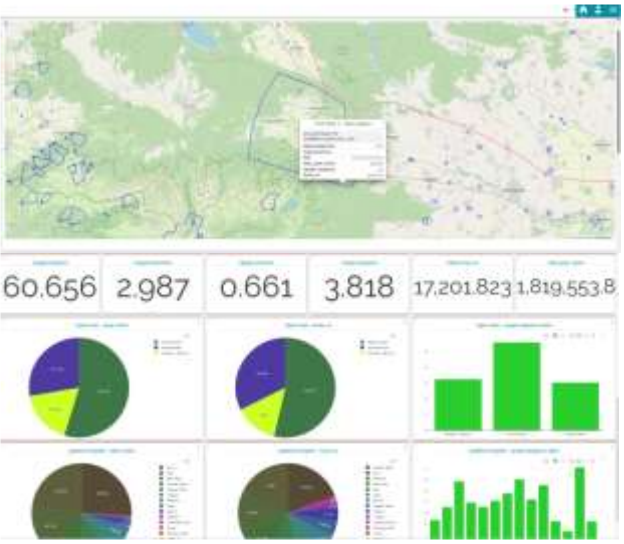

Fig. 5: GIS application - data calculation and visualization

The implemented system enables the generation of detailed reports on forest territories within SPZs by economic region, district, and municipality.

The territory of Bulgaria is divided into 6 economic regions: North-East, North-Central, North-West, South-West, South-Central, and South-East. Each region includes 5 or 6 districts. There are 28 districts altogether, and they are divided into a total of 266 municipalities.

Fig. 6 shows reference data for Sofia City and Sofia District:

- in tabular form on the distribution of forest territories in the 3 SPZs by area, forest type, and age class and
- in graphical form on the distribution of the growth in the 3 SPZs by age class.

To be able to assess the state of ecosystems and ecosystem services and determine their value, we offer concrete practical steps for the implementation of a GIS system for mapping the territorial distribution and characteristics of sanitary protection zones:

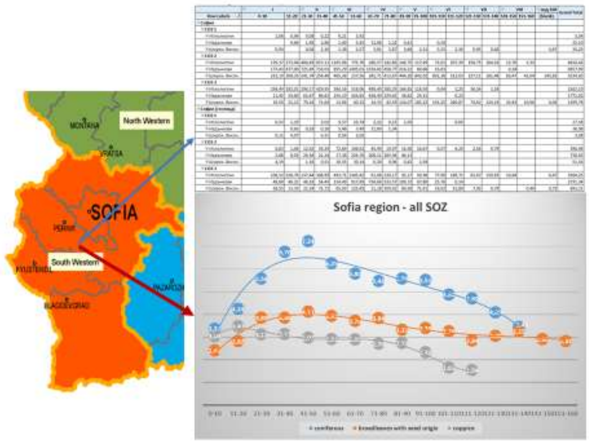

Fig. 6: Reports for Sofia City and Sofia District

1. Generalized layers for the three SPZ belts by applying the DISSOLVE procedure.
2. Intersections between the generalized layers for the SPZs and a spatial layer including municipal boundaries by means of the INTERSECT procedure.
3. Intersections between the national forest layer and the layers obtained as a result of the previous two steps by means of the INTERSECT procedure.
4. Creation of a database containing information on the taxation characteristics of the subdivisions (or parts of subdivisions) falling into the three SPZs.

6 Conclusion

The paper proposes a method for integration of the spatial data of the sanitary protection zones and the database of the forests in Bulgaria in a repository. A GIS system has been designed and implemented to help visualize territorial divisions, water protection forests, and water resources in Bulgaria. This helps to determine the territorial distribution and characteristics of forest areas falling in SPZs in Bulgaria, which have a total area of 576,117 ha and 49.837 million cubic meters of total growing stock.

The reports generated by the system contain data on the distribution of the area, stock, and growth per 1 ha of forest territory by forest group and main tree species.

The results will be used to determine the values of "natural capital" forests and the water ecosystem service. They are crucial for the development of national ecosystem accounts and for assessing the costs and benefits associated with national and regional strategies and plans.

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Conflict of Interest
The authors have no conflict of interest to declare.