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Optimizing the processing of large amounts of spatial data related to the ecosystem water service provided by forest territories

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Abstract: *Nowadays, an increased interest towards the integration of the concept of ecosystem services has been observed, both in regards to processes related to forest and water resources management, as well as in the context of sustainable development of the economy on a local, regional and national level. In the most common case, what is referred to as forest ecosystem services are possible benefits, which man can reap directly or indirectly from ecosystem functions of forest territories. Therefore, it is of great importance to analyse and assess the interactions between the human factor with the conditions and processes through which forest ecosystems create and sustain ecosystem services. The water ecosystem service provided by forest territory could cause the need to process large amounts of spatial data in the form of forest management and hydrological information, as well as information about sanitary protection zones around water sources, in the context of the administrative territorial division of the country at different levels, creates considerable challenges. The difficulties are due to both the various electronic formats in which the necessary information is maintained, and the need to perform different operations on the input data for the purpose of analysis and decision making. The present paper investigates the possibilities of automating the processing of large volumes of spatial data in the context of the ecosystem water service, provided by forest territories by developing a set of tools operating into the environment of open source GIS. The main purpose is to develop a*

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unified approach based on the use of GIS and suitable for the creation and implementation of methods for analysis and management of processes related to the ecosystem water service provided by forest territories. The approach can be applied in different sectors of the economy, public relations and the environment.

Keywords: GIS, water ecosystem service, forest territories

Introduction

Water is considered a public natural resource, and due to this characteristic it is declared to be State property (Art. 18, Para. 1 of the Constitution of the Republic of Bulgaria and Art. 11 of the Water Act) [1, 2]. According to Water protection and production functions in forest management models (2011), from an economic point of view it means: first, being a natural resource the monopoly on this specific property belongs to the State. The State has the exclusive right to assign some of its property rights to other business entities. Generally, this right of use is assigned to entities whose economic objective is the industrial supply of drinking water, irrigation, etc. It is not rare the water management entities to have complex objectives. Irrespective of the economic objectives, the mechanism for assigning the right of use forms a new monopoly – the monopoly of water management. This is the second feature: the establishment of this second monopoly. This new monopoly gives exclusive rights to the water management entities to generate income from water not as a natural resource but as an economic wealth having a certain market value. The market value includes the fixed and variable costs, and the net financial income obtained by the respective water management entities. As it can be expected, the costs should include the amount which the State, as the exclusive owner of the water natural resource, should obtain from the economic realization of its property. For the right to use water from surface and groundwater sources, a fee should be paid (Art. 194, Para. 1, Item 1 of the Water Act) and accumulated by the Enterprise for Management of Environmental Protection Activities (EMEPA) (Art. 196, Para.1, Item 1 of the Water Act) at the Ministry of Environment and Water (MoEW).

The issue on the expedience of such economic relationship arises, as the greater part of the water natural resource is the product of forests in general and of water protective forests in particular [3]. An increased interest towards the integration of the concept and instrumentarium of ecosystem services, both in regards to the processes related to environmental management, as well as in the context of sustainable development of the economy on a local, regional and national level has been observed in recent years. In the most common case, what are referred to as services are possible benefits, which people and society can reap directly or indirectly from ecosystem functions.

The water protective forests on the territory of Bulgaria cover the area of 248 943 ha, which is 6,1% of the forestland, 72,64 % of which are state property, 11,41% - property of municipalities, 9,89% - private

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property and 6,06% - other (REF). Water protective forests annually accumulate between 1-1,5 billion m^3 of water. By nature, these forests act as a multi-year reservoir from which a steady runoff of pure water is formed yearly, which through the water management infrastructures reaches water users and consumers.

In this context, the need to develop appropriate tools and procedures for automating processing of large amounts of data related to ecosystem services assessment and mapping, and especially the "water" ecosystem service and forest territories, becomes a key task in the design and implementation of a wide range of computer applications. Such automation could facilitate both the quantitative assessment of services in economic, social or other aspects, as well as the making of adequate final management decisions. Since ecosystem services and forest territories have a distinct component related to their geographical positioning, the application of established information technology, such as GIS and DBMS, would significantly expand the existing set of tools for analysis and decision-making by the upper management of organizations and businesses, regarding the proper assessment of the "water" ecosystem service.

This study aims to explore the possibilities for automating the procedure for processing and analysing large arrays of spatial and statistical data related to the water ecosystem service, forest territories (state forests), and administrative territorial division for the purposes of the economic statistics of the country. It covers issues related to the current regulatory framework and requirements at national and regional level, the scope and capabilities of the defined tools for the automation of GIS tasks and database management systems in light of the problem addressed, as well as the possibilities for creating synergies between them and addressing the problems associated with the correct character encoding. The study also looks at the main procedures and their sequence of application in a single algorithm which allow for the analysis to be automated at economic region and municipal levels. The practical application of the results is tested in the Northwest and South Central economic regions.

Key characteristics of the current regulatory framework

Ecosystem services are an interdisciplinary area between ecology and economy. According to Nikolov [4], the term "ecosystem service" was first used by Ehrlich & Ehrlich [5] in the context of linking the concept of ecosystems and services. They are the conditions and processes by which natural ecosystems and the organisms that compose them, sustain and fulfil their lives. These services preserve biodiversity and the production of ecosystem goods and benefits. Ecosystem services are also the benefits that a person derives directly or indirectly from ecosystem functions.

The study and analysis of the specific characteristics of the water ecosystem service in light of the assessment of the impact of forest territories are linked to the scope of the current regulatory framework of the Republic of Bulgaria. Moreover, in order to achieve the goals set in such a comprehensive study comprising ecological, social and economic aspects and covering the whole territory of the Republic of Bulgaria, the

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influence of the administrative territorial division of the country should also be taken into account. Within the scope of the study of the specific characteristics of the water ecosystem service, the sanitary protection zones constitute the first important factor to be assessed. Technical and technological issues related to the sanitary protection zones around water sources and facilities for drinking and household purposes and around mineral water sources used for medical, prophylactic, drinking and hygiene purposes form the basis for Ordinance No 3 adopted in 2000 [6]. The ordinance applies to sources of drinking water relevant for commercial or social purposes and it defines the scope of the sanitary protection zones, namely the water area and the territory around surface water sources and facilities for drinking and domestic purposes, as well as the territory and/or the body of groundwater around groundwater sources for drinking and domestic purposes and of mineral water sources used for medical, prophylactic, drinking and hygiene purposes, and the territory around aboveground facilities. The ordinance determines three clearly defined belts within the sanitary protection zones as well as the methods for their formation and determination of their boundaries.

The content, conditions and procedures for the creation, maintenance and storage of the mapped forestry data are consistent with the requirements of Ordinance No 20 of 2016 [7]. In the context of the Cadastre and Land Register Act [8], these are specialized maps which include not only all necessary information from the cadastral map, but also specialized data on the boundaries of the subdivisions of forest areas, qualitative and quantitative data on these subdivisions, etc. According to Ordinance No 20 of 18 November 2016 on the content, conditions and procedure for the production and maintenance of forestry maps [7], the main purpose of this georeferenced information is to support a wide range of activities, the most important of which in the context of the water ecosystem service are: maintaining up-to-date information on forests and forest activities; supporting the processes of elaboration of forest management plans and programs, as well as plans for the management of protected territories; elaborating plans for the protection of forest territories from fires, etc. According to Act on the Administrative and Territorial Structure of the Republic of Bulgaria [9], the information is maintained by territorial forest divisions and by local administrative units. The latter correspond to territorial units LAU level 2 within the meaning of the Regulation [10]. Another important characteristic which should be taken into account when addressing the issues associated with the automation of the procedure for the processing of data on the water ecosystem service and the assessment of the impact of forest territories is the specific nature of the ZEM electronic format, which is used to store spatial and specialized data on forests and forest resources.

Regulation (EC) No 1059/2003 of the European Parliament and of the Council [10] on the establishment of a common classification of territorial units for statistics using the nomenclature of territorial units for statistical purposes (NUTS), as last amended in 2017, is in force within the EU. The Regulation is intended to enable the collection, compilation and dissemination of harmonized regional statistics in the

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Community in cooperation with the national statistical institutes of the Member States. In addition, in each Member State the local administrative units (LAU) subdivide NUTS level 3 territorial units into one or two additional levels of territorial units. The NUTS classification defines three NUTS levels, and for the purposes of the study intended to investigate the water ecosystem service it is necessary to assess the data related to NUTS2, namely the six economic development regions (Southwest, South Central, Southeast, Northeast, North Central and Northwest regions). The assessment in the context of the local administrative units is based on the current Act on the Administrative and Territorial Structure of the Republic of Bulgaria [8] and covers the regions and municipalities (NUTS3 and LAU1 respectively within the meaning of the Regulation [10]), where for the purposes of the study the assessment and analysis were made at municipal level with possibilities for further data aggregation at regional level.

The consideration of the abovementioned factors and limiting conditions determines the scope and type of procedures that need to be laid down, as well as their implementation sequence in the preparation of the digital model for the analysis and study of the water ecosystem service within forest territories. The conducted analysis of the regulatory framework concerning the issue in question shows that, on the one hand, there is a need to aggregate data on forest territories from municipal through regional to economic region level, and, on the other hand, there is a need to differentiate data on sanitary protection zones from economic region through regional to municipal level. The large amounts of data which need to be studied and analysed for the purposes of addressing the abovementioned issues, including spatial data, highlight the importance of automating the processes related to the construction of a digital model and related information arrays in order to increase efficiency and reduce the time necessary to perform routine operations, which due to their large amount could easily result in the accumulation of human or systematic errors that could adversely affect the results obtained. The amounts of spatial and statistical data available require the development and integration of both GIS and DBMS tools.

Material and Methods

Automation tools

As Milchev & Myashkov [11] and Asenova & Milchev [12] point out, the development of specialized software which works in a GIS environment enables the performance of a wide range of tasks which significantly expand the standard tasks of the desktop GIS software. These tasks can range from the creation of intuitive graphic user interfaces intended to facilitate GIS users in their interaction with specific digital models and implementation of specialized tasks to the development and implementation of specialized analysis modules using numerical methods or the formalization of complete business processes related to the application of GIS in making justified final management decisions. With recent IT developments, users have

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gained access to a wide range of programming languages that they could use successfully in various GIS applications. According to Cioloboc [13], these include languages such as Java, C, C++, Python, C#, Visual Basic .NET, etc. Naturally, the type of the application under development determines the choice of the language. In this specific case, the automation is intended to work in a desktop GIS environment. Therefore, the language choice has been narrowed down to the system languages supported by these systems, namely Python. This interpreted language cannot offer a very high speed of execution to the developed applications compared to the compiled platforms. However, it is widely available on a large number of desktop GIS (both for commercial use and free of charge, including ArcGIS, QGIS, GRASS GIS and gvSIG), provides access to well-organized standard libraries and supports easy migration of created resources between different desktop GIS if the user is familiar with their built-in object models. What proved extremely useful in the present study was the ability to perform operations within the file system, as well as the ability to support JSON as a file format.

The large amount of statistical information (from external sources or extracted from ZEM files), which is relevant to spatial data on sanitary protection zones, forestry information and administrative territorial division for statistical purposes requires the integration of DBMS to store, analyse, extract and link the necessary data. At the same time, due to the availability of a large set of specialized processes and functions, automation processes must take into account the use of spreadsheet tools for analysing the water ecosystem service.

The big commercial and free office products like Microsoft Office and OpenOffice contain both the necessary software products, such as a spreadsheet editor and DBMS, and process automation through the use of script languages such as Visual Basic for Application [14] and OpenOffice.org BASIC [15]. In this case the automation was performed using Microsoft Office 2019 due to its expanded set of features that simplify the work with office objects, perform system operations with file system objects, execute http requests to retrieve specific data from online sources, and last but not the least, due to the procedures and functions for analysing forestry data developed by the members of the team at an earlier stage.

The conducted preliminary study found great differences in the encoding of textual strings retrieved from different information sources, and especially in the information used in the attribute data related to the spatial data used. The encodings used include DOS, Windows-1251 and UTF-8. This strongly limited the capacity of data from different information sources to be connected and queried for the purposes of automated data processing related to the analysis of the water ecosystem service in the context of forest territories. This necessitated the use of a procedure for automated recognition of the encoding used and conversion of primary data to UTF-8 developed by the members of the team for another research task. The primary data format did not allow the data to be connected at text string level due to the incompatibility of the characters in the three

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encoding tables used (Figure 1). This required the use of an automated procedure for batch processing and conversion of the encoding tables.

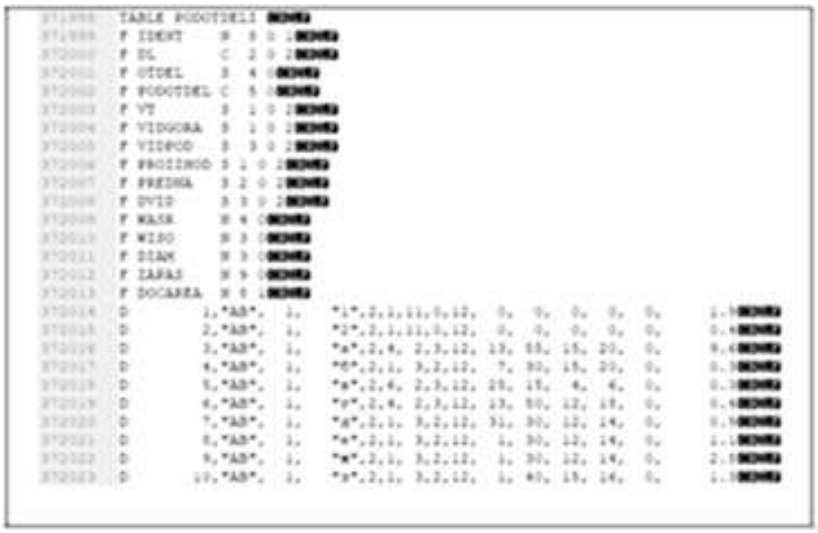


Figure 1. Specialized data retrieved from the ZEM file in the original form

Analysis of the water ecosystem service in the context of forest territories

Taking into account the impact of the administrative territorial division and the nomenclature of territorial units for statistics, the procedure for the automation of the processing of the input data necessary for the analysis of the water ecosystem service in the context of forest territories has clearly defined phases and data flow direction. Figure 2 shows the main phases of the processing procedure and the data flow direction.

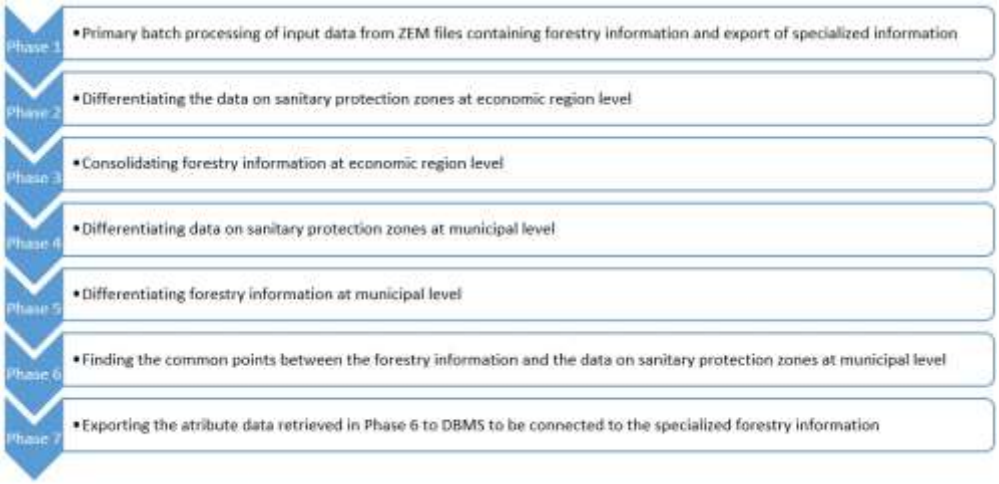


Figure 2. Information processing algorithm main sections and data flow

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The preliminary phase preceding the automated processing procedure starts with selecting an economic region, determining the administrative territorial units that fall within it, as well as the divisions of the regional forestry directorates that are fully or partially located in that economic region. This is a necessary step because forestry information is connected at cadastral subdivision level (LAU level 2) and the analysis of the ecosystem service is made at municipal level (LAU level 1), with subsequent consolidation at regional level (NUTS3) and economic region level (NUTS2). Figure 3 shows the cases of full (Northwest region) and partial inclusion (South Central region). The Northwest region includes the territories of 23 state forestry and hunting enterprises, which are part of the Regional forestry directorates of Berkovitsa and Lovech, and their territorial divisions fall entirely within the scope of the processed economic region (Figure 3A). This is not the case with the South Central economic region which covers the territories of state forestry and hunting enterprises falling within the scope of 5 Regional forestry directorates, including Pazardzhik, Plovdiv, Kardzhali, Smolyan and Sofia. In this specific case, as it can be seen in Figure 3B, the territory of the economic region partially includes a forest fund managed by the Regional forestry directorate of Sofia. The attribute data have been pre-processed in order to convert their original encoding to a unified encoding consistent with the subsequent processing.

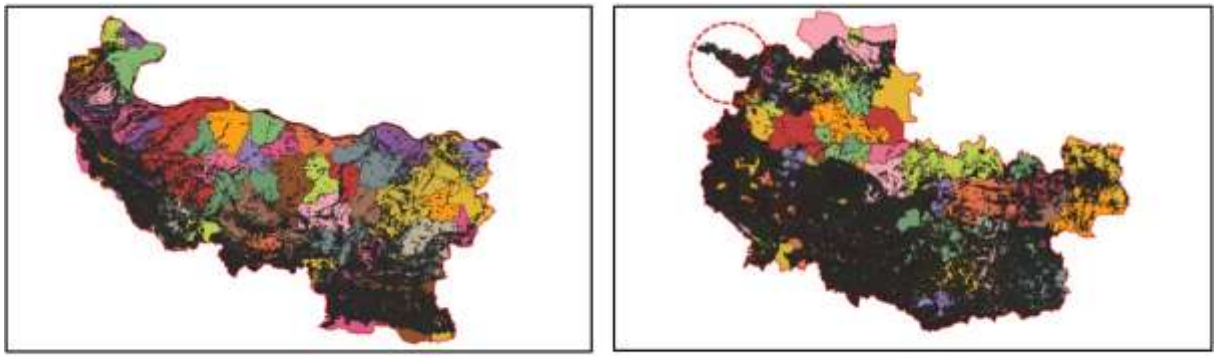


Figure 3. Spatial data in the preliminary phase used as a starting point for automated processing (A-Northwest economic region; B-South Central economic region)

Based on the data obtained from the preliminary phase, a procedure was developed for the implementation of Phase 1, which sends the corresponding ZEM files to publicly available forest management projects found on the website of the Executive Forest Agency for batch processing, extracting specialized data and presenting them in tabular form in a spreadsheet in MS Excel format. The structure and content of the fields in the tables are analysed: Technical divisions table; Additional data on subdivisions table; Current composition of the subdivision table; Future composition of the subdivision table. The output data from this

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phase are transcoded and stored in a format that allows their automated processing in DBMS or spreadsheet environment, as well as their correct integration with the corresponding spatial data in a desktop GIS environment if necessary.

Results

The successful implementation of Phase 2 of the automation procedure required the development of a procedure for checking the integrity of spatial data due to the problems identified during the preliminary study phase caused by polygons within the sanitary protection zone data layers, as well as a procedure for finding the common points between the layers with vector data on the economic region and the three belts of the sanitary protection zones. The results for the Northwest region are shown in Figure 4A. Phase 3 involves a similar operation related to the identification of the common points between the forestry information and the data on the economic region, preceded by an operation for consolidating the data on the different divisions of the relevant regional forestry directorates which are fully or partially located within the economic region. The results of the implementation of the automated procedures are shown in Figure 4B.

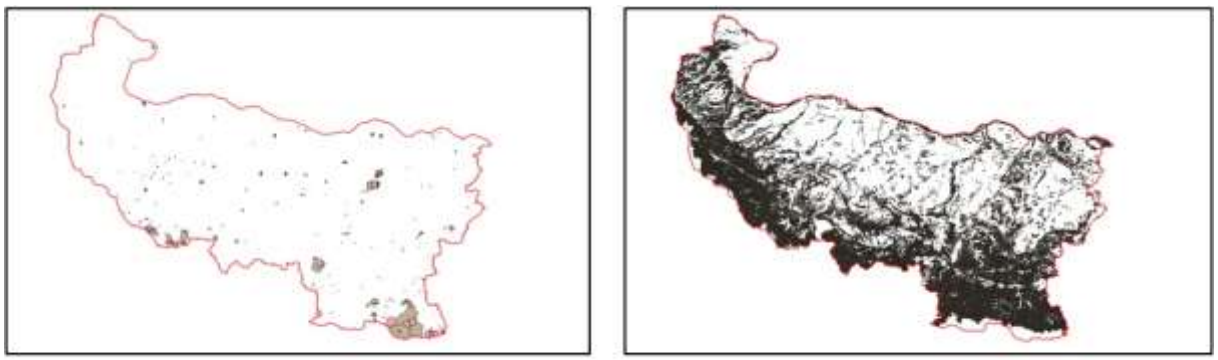
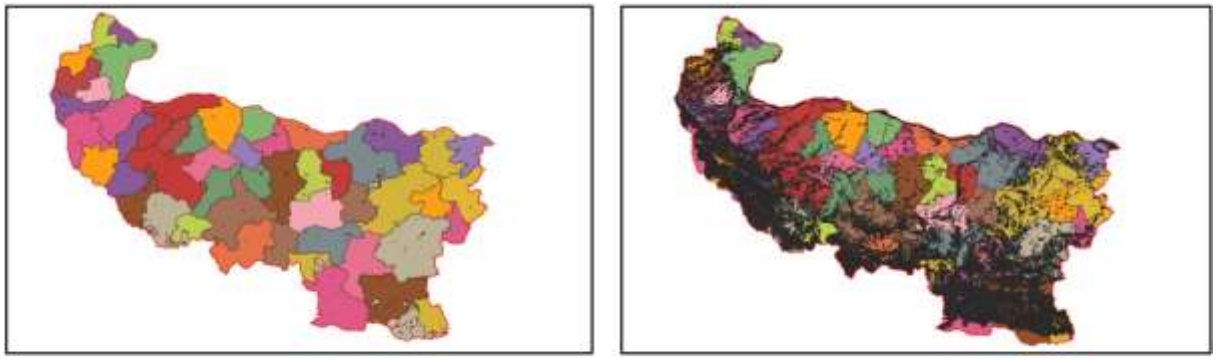


Figure 4. Results from the automated procedures used in Phase 2(A) and Phase 3(B) for the Northwest economic region

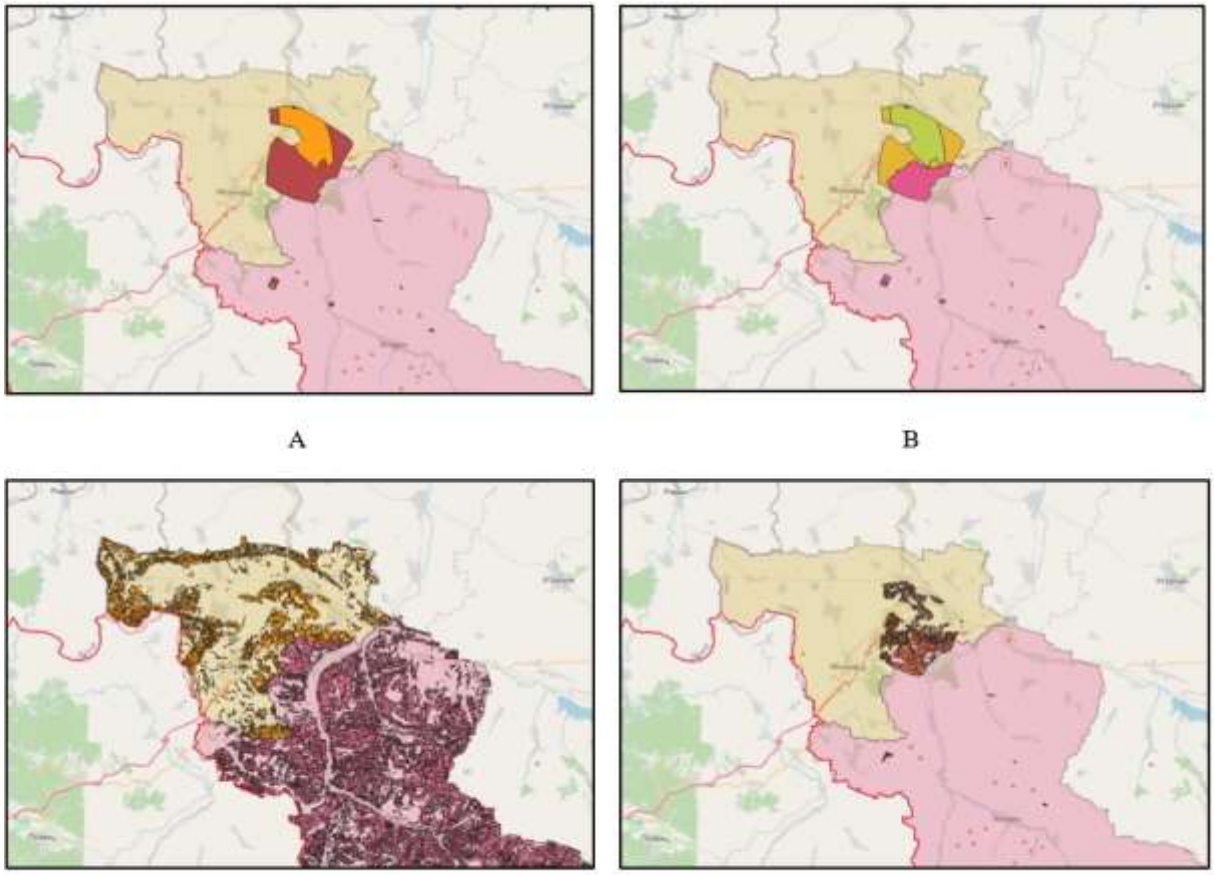
Phase 4 and 5 required the use of the procedures developed for differentiating the data on the sanitary protection zones and forestry information at municipal level necessary for the analysis of the water ecosystem service. Apart from the automation of operations performed with the data from the respective vector layers (municipalities, sanitary protection zones in the Northwest region and forestry information on the Northwest economic region), procedures have been developed that calculate the areas of forests and sanitary protection zones by municipality, as well as the forest area that falls within the respective belts of the sanitary protection zones.

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A B

Figure 5. Results for the Northwest economic region from the applied automated procedures in Phase 4(A) and Phase 4(B)



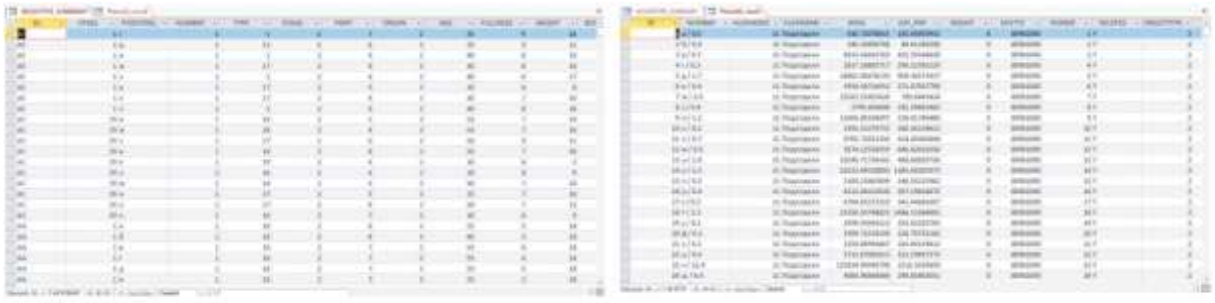
A B C D

Figure 6. Results from the implementation of Phase 4, Phase 5 and Phase 6 for Yablanitsa and Teteven municipalities using the basemap of Open Street Map (A-belts of sanitary protection zones for the Northwest region, B-belts of sanitary protection zones by municipality, C-forest cover by municipality, D-forests falling within sanitary protection zones by municipality)

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Based on the preliminary study of the data from the forest layer, a procedure was developed to remove the data included in some forest management projects which cover municipal territories, dams, etc. that greatly limit or hinder the possibilities for automation of the processes related to the extraction of the necessary information and its subsequent analysis. Figure 5 shows the results from the applied procedures for analysis and extraction of the necessary information on the sanitary protection zones by municipality and forestry information by municipalities falling within the Northwest economic region. Phase 6 is aimed at finding the common points between the information processed in Phases 4 and 5. Figure 6 shows the detailed results from the implementation of Phase 4, 5 and 6 for Yablanitsa and Teteven municipalities falling within the Northwest economic region.

The performance of the tasks set in Phase 7 required the development of a procedure for batch processing of the layers obtained in Phase 6 and extraction of the attribute data from the spatial data obtained as a result of the processing done in the previous phases. The information is recorded directly in the DBMS, which allows its subsequent connection, decoding and export for analysis with the possibility of applying a variety of research methods (quantitative, statistical, etc.) necessary to achieve the objectives for the assessment and analysis of the water ecosystem service at different levels.



A B

Figure 7. Results in a DBMS environment (A-summarized information on tree species by division and subdivision, B-results obtained from the processing in Phase 7)

The DBMS stores the data from the specialized forestry information contained in the tables of the ZEM files of the forest management projects, as well as the necessary classifiers for decoding the information from the attribute tables, including classifiers for: tree species, terrain, depth, economic class, stratification, area, sub-belt, exposition, etc. (in accordance with the annexes of Ordinance No 20) [6]. Figure 7 shows an example of a table containing information on tree species by division and subdivision, summarized for forest areas containing state forests falling within the scope of the Northwest economic region.

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Discussion

The questions related to the analysis and assessment of the ecosystem service "water" in context of forest territories, administrative-territorial division and division of economic areas pose complex research challenges that require processing and analysis of large amounts of primary information. In a major part information related to forest uses, along with factors such as area of forest properties, forms of ownership and others, is part of forest management projects, plans and programs. In this respect, forestry projects represent the source that provides the highest level of detailed in-formation, which, in turn, is necessary in the formation of a primary information basis for carrying out analysis and assessment of the ecosystem service "water" - both for state and municipal forests, as well as for private ones. In the course of created study, several characteristic features were noted that hinder effective processing (including using automated procedures, developed specifically for the purpose), and to some extent the subsequent analysis in connection with the implementation of the present scientific research task, namely:

• Forest management projects are carried out at the level of the state forest farm, state hunting farm or educational experimental forestry, as there are no publicly available sources summarizing this information on level of the regional forest directorate.

• Forest management projects are designed for a period of ten years, but unfortunately, for the different forestry units, they do not begin to perform at the same time, resulting in complicated procedures when updating basic information for analysis. For the purposes of the current study relevant forestry projects were covered at the time of research, and a procedure was developed that would update forest information at a forestry layer level for the whole territory of the Republic of Bulgaria.

• The forestry division uses an administrative-territorial division of the country at land level (LAU5). This makes it difficult to unify the researched primary information to an administrative division level because in a state forestry or a hunting farm, lands (LAU5) may be included, which in general can be positioned in different municipalities and even districts, which are core units for territorial management.

The development of appropriate procedures to automate this process significantly shortens processing time, provides opportunities for follow-up analyses using data-bases and spreadsheets and creates the necessary prerequisites that ensure the avoidance of any errors caused by the different interpretation of input data by operators. The forest managing projects use a data storage format, including spatial and statistical information that is not suitable for processing within the environment of the most common GIS applications. This imposed, in connection with the present research, the form of data storage to be analysed and appropriate procedures to be developed for the processing and extraction of the necessary information related to the assessment of the ecosystem service "water". Additional controls for validating information were developed because within the processing activity, problems with the stored georeferenced information within the forestry

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projects were detected, i.e., problematic polygons or used coordinates. The developed validation procedure, provided the adequate primary information for the subsequent analysis.

The prerequisites for the successful application of the developed automation methods in present study are the capabilities that are offered by the modern GIS software and office products, especially the built-in capabilities for using programming languages. Modern software includes products, which possess a toolkit that allows solving complex problems, both in the field of processing and analysis of geospatial information, as well as in the processing and analysis of large amounts of structured tabular information, that are interrelated. These operations are suitable in case of low detail levels, from an administrative-territorial point of view or at an independent forestry unit level. The analysis of the ecosystem service "water" requires a significant volume of accumulated information from various sources, including at a data transformation and validation level. Precisely in instances of these problems, the programming tools embedded in modern software products prove to be the key to the successful solution of the present task, as they significantly reduce the time required to accumulate information and reduce the time of the subsequent extraction, analysis and processing. In this way, the possibilities of introducing operator processing errors, especially in the more complex extraction and analysis procedures, are reduced.

The approach developed for the purposes of automated data processing and analysis, related to the service of aquatic ecosystems, can relatively easily be migrated to other GIS software, databases, and spreadsheets once it is made compatible with the relevant object models. Due to the developed procedures for automated processing and analysis, the study of information has been made possible, both at different levels within forestry policy, as well as within the different administrative territorial and economic levels, which turns the obtained results into a powerful tool that supports the decision-making management process at different levels and the formation of policies in the short, medium and long term.

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[2] Constitution of the Republic of Bulgaria, promulgated in State Gazette No56/1991, in force since 13 July 1991, amended and supplemented in State Gazette No 85/2003, amended and supplemented in State Gazette No 18/2005, SG No 27/2006, State Gazette No.78/2006 – Decision No 7 of the Constitutional Court of 2006, State Gazette No 12/**2007**.

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