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GIS-BASED ASSESSMENT MODEL OF RESILIENT MANAGEMENT AND MONITORING OF WATER RESOURCES

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Introduction. The management and efficient use of water resources is a crucial and extremely acute problem. This study focuses on geographic information systems (GIS) as a tool for the resilient management and monitoring of water resources. The objective was to create and implement a GIS-based model for managing and monitoring water resources by developing a system of indicators. This model presents future scenarios for Bulgaria based on the assessment of indicators for resilient management and the efficient use of water resources.

Aim and tasks. This study aims to develop and implement a GIS-based model that integrates technical, economic, social, and environmental indicators for the resilient management and monitoring of water resources in Bulgaria. This study focuses on opportunities to improve the effective management and rational allocation of water resources in Bulgaria using geographic information systems.

Results. A comprehensive system of indicators for assessing sustainable water management in Bulgaria was developed, considering economic, technical, social, and environmental criteria. The calculation of the composite index showed a low level of efficiency, and the main problems were water losses during transportation of up to 55-60%, a reduction in investments in wastewater disposal by 40% (2016-2023) and a low level of reuse of treated wastewater. The GIS-based model revealed significant territorial differences in the state of water resources and consumption in Bulgaria. Key problems include high losses in the water supply network, water use for hydropower, and poor water infrastructure, which affect the resilience of water management. Irrational consumption and storage may lead to serious water supply issues in key regions of the country.

Conclusions. Geographic information systems enable the improvement of water resource management by integrating and processing large amounts of data. In response to the identified research questions, the current state of Bulgaria's water sector was analysed and assessed. The key factors affecting the sustainable management and use of water resources and territorial imbalances in rational water use were identified. Developing a comprehensive strategy that includes infrastructure modernisation, introducing water-saving technologies and improved management efficiency can overcome structural problems in the water sector and prevent water resource shortages.

Keywords: GIS Model, Water Management, Resilience, Resources Efficiency, Sustainability.

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1. Introduction.

Water resources are a key strategic factor in socio-economic development, ecological balance, and quality of life. The growing problems related to climate change require the effective and sustainable management of water resources. With its diverse hydrographic distribution and significant regional differences in availability and use, Bulgaria faces several challenges related to inefficient water consumption and optimisation.

Modern water resource planning and management require adopting an integrated approach and multi-sector information, including hydrological data, infrastructure parameters, socio-economic indicators, and environmental assessments. In this context, geographic information systems (GIS) offer a technological framework for collecting, processing, analysing, and visualising spatial data, which allows for a comprehensive assessment of the state of the water sector and informed management decisions.

The development of GIS-based models for resilient management and monitoring of water resources provides an opportunity to apply multi-criteria assessment methods, integrate data from different sources, and simulate development scenarios. Such models help prioritise investments, reduce network losses, optimise irrigation systems, and limit negative environmental impacts.

This study aims to develop and implement a GIS-based model that integrates technical, economic, social, and environmental indicators for the resilient management and monitoring of water resources in Bulgaria. The model allows for assessing the current state of the water sector and water resources by region. Based on the assessment, scenarios of future development of the water sector in the country were implemented in the model. The proposed model can support water resource management in Bulgaria.

The main research questions are as follows:

RQ 1. What is the current state of the water sector in Bulgaria?

RQ 2. What are the main problems and factors affecting the resilient management and use of water resources?

RQ 3. What are the territorial differences in terms of the rational use of water resources in Bulgaria?

RQ 4. What would be the future development trends of the water sector in Bulgaria under current conditions?

2. Literature Review.

Resilient water resource management is embedded in a few national, European, and global strategic documents and publications in the academic literature. The distinctive feature of this study is the proposed model for assessing the effective management and use of water resources in a territorial plan, considering the main factors for achieving sustainability (Aznar-Sánchez et al., 2018).

It is necessary to clarify the use of the two terms “Resilience” and “Sustainability”. In many cases, these two terms are used as synonyms. However, there are some differences between these two approaches. The triple result of ecological, social, and economic systemic considerations defines sustainability. Resilience is viewed as the ability of a system to counteract harmful impacts and threats, recover and adapt after an event, or a change in the environment (Marchese et al., 2018). In this study, the sustainability of water resources was considered through the prism of their effective use and the impact of human activity. In this regard, the concept of “Resilience” is adopted, considering the dimensions of sustainability.

Research has explored the importance of water resources and the possibilities for their more effective management. Water is a key resource and is the basis for the functioning of all economic sectors (Velichkova et al., 2020). Javadinejad et al. (2019) reviewed the challenges of assessing sustainable water management, the barriers to sustainable water development in various sectors, and international practices to mainstream sustainability in water-related decision-making.

These factors are at the heart of the efficient use of water resources as a key resource for economic development (Koval et al., 2023; Szopińska & Ramczyk, 2024). Rationalising water resources and properly treating wastewater are key to achieving a circular economy (Mikhno et al., 2021).

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Simultaneously, companies within the circular economy are often fast-growing due to the specific innovations they apply (Anguelov et al., 2023). Adopting a systemic and spatial approach is key to studying sustainable water management. The development of resilient systems remains challenging owing to the wide range of economic, environmental, and social factors that must be considered throughout the system's life cycle.

First, the function and boundaries of the system are identified, then the system (including its requirements) and its expected performance are designed, and finally, the system is implemented.

The spatial approach is dictated by the specifics of the territory and its water resources. Sustainable water management is the basis for sustainable territorial/regional development (Tsonkov & Petrov, 2024). Kucher et al. (2023) examined the sustainability and effectiveness of water management and these factors' role in sustainable regional development. A differentiated approach to sustainable water management was proposed, depending on the type of region (territory) considered. However, introducing such systems requires a proper approach from the organisation's management; this process must be considered a significant organisational change that should be managed purposefully to be effective (Anguelov & Angelova, 2023).

Effective water management requires the integration of information and communication technologies into management processes. The geographic information system (GIS) is a key tool in this regard. Further, different approaches to water resources modelling using GIS were studied, and the models can also be applied in practice for monitoring and management (Pal et al., 2025).

Tsihrintzis et al. (1996) have made a detailed review of the applications of GIS and highlighted the directions for using GIS in areas such as: modelling of surface hydrology and groundwater, modelling of water supply and wastewater systems, including stormwater and pollution, and other related applications. GIS is the foundation of modern decision support systems for water management activities.

Rata et al. (2014) studied the integration of decision support system (DSS) concepts into GIS and their relevance to water management concerns. The specifics of water resources management require an adapted approach to the development of data structures in the GIS system. By modelling data in GIS, various models describing specific objects in the water sector can be derived (McKinney & Cai, 2002).

Water resource management is at the core of modern concepts for managing cities and regions during digital transformation. Spatial data processing is essential for effective water management. Zhao et al. (2025) proposed an integrated ICT-based methodology that includes building a digital twin ecosystem using IoT sensors, GIS layers, remote sensing images, and game engines.

Measuring the effectiveness of water resource management is at the core of assessing the development and design of policies to achieve resilience to climate change. Subsequently, a system of performance indicators was proposed that are critical for assessing the implementation of environmental management plans (EMPs) in the water sector, and an attempt was made to model the relationships between the performance indicators of water projects (Farouk et al., 2024). The developments and data processing methods (Baeva & Khinova, 2025) have enabled identifying the characteristics and trends of harmful emissions and other primary pollutants. This served as the basis for further analysis and processing of data related to environmental pollution, particularly water pollution. Kotenko et al. (2023) propose a methodology for assessing the economic efficiency of greening in water resources management and water use by enterprises.

The gaps in the literature are that many studies remain at the level of strategic declarations, and there is no practical implementation of the goal of sustainable water management. The terms "sustainability" and "resilience" are often used synonymously, creating confusion. A multidimensional approach combining environmental, economic, and social factors is rare, and management models are not sufficiently adapted to territorial specifics.

Despite the potential of GIS and digital technologies, their implementation is limited by organisational and technical barriers. Finally, there are no holistic indicator systems for assessing the effectiveness of water management, especially considering the circular economy and water reuse aspects.

Developing integrated models and assessment systems based on GIS and digital technologies is key to building resilient and sustainable water systems worldwide. Only an integrated approach that combines technical, economic and managerial measures can ensure the sustainability of water resources and their rational use at the regional and national levels.

3. Methodology.

This study is based on an adopted systemic and territorial approach. The data included in the analysis have spatial dimensions. In this regard, the study is spatially limited to Bulgaria. The data used were mainly from the National Statistical Institute (NSI), the Ministry of Environment and Water of the Republic of Bulgaria, the Ministry of Regional Development and Public Works of the Republic of Bulgaria, and the Basin Directorates for water management. For the needs of this study, the necessary data are spatially structured by districts and municipalities (the main format for providing and collecting data from the National Statistical Institute), as well as by basin directorates for water management.

The data used include the following categories: Population by districts and municipalities; Production by districts and municipalities; Income and expenses from the activities of enterprises by districts and municipalities; Expenditures for environmental protection and restoration; Expenditures on long-term tangible assets and long-term intangible assets; Water abstraction by sources; Water distribution by Public Water Supply; Water used by economic activity; Water used by households; Generation and discharge of wastewater; Operating urban wastewater treatment plants; Water supply and sewage network; Population and water services.

The study data outline the main factors influencing resilient management and efficient use of water resources.

The factors that had a significant impact on the use of water resources were grouped into the following categories:

– Economic factors describe the productivity and profitability of water resource use. This also includes the costs of water resource use and its recovery. This criterion describes the efficiency of the water consumption.

– Technical factors describe the state of the infrastructure and the provision of the territory with the necessary technical means. This criterion describes the efficiency of the water supply and sewage infrastructure.

– Social factors describe providing water resources and services to the population. This criterion allows the population to assess the efficiency of water resource consumption.

– Environmental factors describe the efficiency of wastewater management and use. This criterion allows for assessing the impact of water resources and wastewater utilisation on the environment.

All factors have spatial and territorial dimensions. These criteria form a system of indicators for assessing the resilient management of water resources in Bulgaria.

Other factors that significantly impact water resources may be climatic factors, such as precipitation, temperature, evaporation, and geographical factors, such as altitude, slope, soils, and erosion risk. Despite their significant impact on the water sector, these factors were not included in the model because they are difficult to influence.

Based on the factors included in the model, a forecast was made for Bulgaria for 20 years. The forecast was implemented using the ArcGIS Online geographic information system.

4. Results.

4.1. Water Sector Management in Bulgaria.

In Bulgaria, administrative structures implement water management at national and territorial (regional) levels. The ownership of water, water bodies, and water management systems and facilities can be state, municipal, or private (Ministry of Environment and Water, 2023).

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The Ministry of Environment and Water (2025) implements water management policies at the national level that aim to create and maintain appropriate conditions for all water resources and limit their negative impacts. At the territorial level, Basin Directorates manage water and assist in implementing water management policies.

The basin (territorial) level of water management is carried out by four Basin Directorates for the management of the territory of four water basin management regions. The borders of the regions run along the watersheds of the river catchments within the scope of the state borders (Ministry of Environment and Water, 2025).

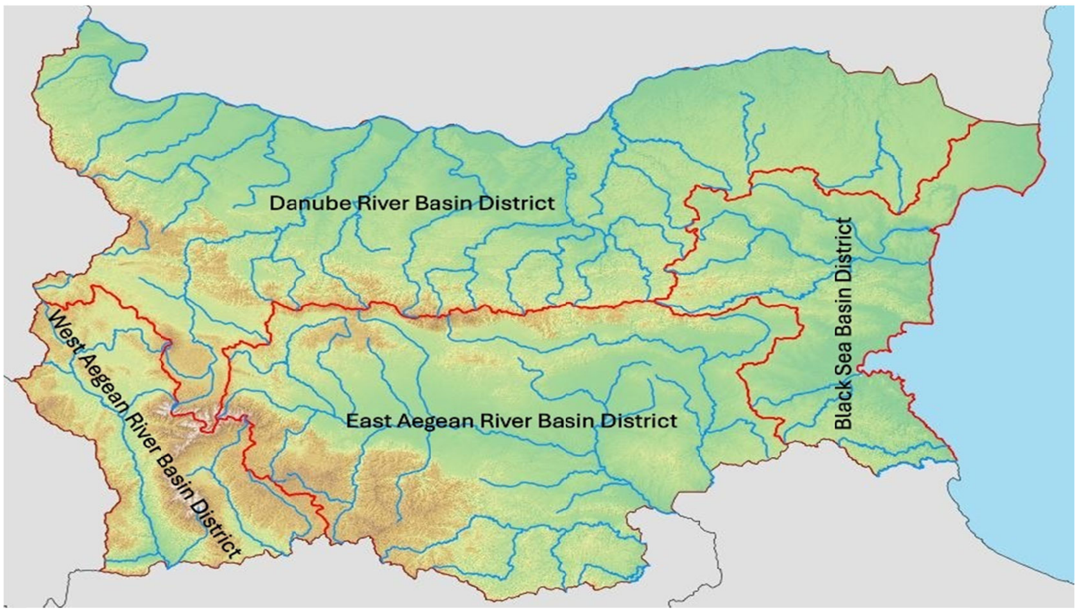

Fig. 1. Borders of the Basin Management Directorates in Bulgaria, 2025.
Source: based on Ministry of Environment and Water (2025).

The region includes the main river basins of the Danube River in the territory of the country, with a total area of 47,230 km2, or 42.5% of the country's territory. Pleven is the centre of this region. It covers the territory of 2,278 settlements in 18 administrative districts, including the capital Sofia.

The region covers the watersheds of the Iskar, Ogosta, Nishava, Erma, Vit, Osam, Rusenski Lom, and Yantra rivers and the waters of the Danube River. The Danube region has approximately 3 million people, representing approximately 45% of the country's total population. The Black Sea region, with its centre in Varna, includes the watersheds of the rivers flowing into the Black Sea and covers the territories of all the Black Sea municipalities in Bulgaria. Its territory has 9 main river basins and 40 groundwater bodies from seven aquifers. The region's territory includes the territories of 8 administrative districts, 47 municipalities and a total of 633 settlements.

The population of the region is over 1 million people, which is approximately 16% of the country's population. The territory of the Black Sea region is one of the territories most threatened by water shortages.

The Eastern Aegean Region occupies the central part of Southern Bulgaria and has an area of 35,227 km², which represents approximately 32% of the country's territory. The region includes the watersheds of the Tundzha, Maritsa, Arda and Byala Reka rivers. The region is centred in Plovdiv and encompasses 10 administrative districts, 90 municipalities (81 municipalities in full and 9 in part), and 1,769 settlements (81 cities and 1,688 villages). The region has a population of approximately 2 million people, which is about 30% of the total population of the country.

The West Aegean Region is in Southwestern Bulgaria and covers 11,965 km², or approximately 11% of the country's territory.

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The West Aegean Region is centred in Blagoevgrad and includes the watersheds of the Struma, Mesta, and Dospat rivers. The region includes settlements in six districts and 32 municipalities. The population of the region is approximately 550,000, which is nearly 8% of the population of Bulgaria.

The Basin Directorates manage the water sector in the territory of the basin management region and are located in the centres of the regions. These directorates have basic functions in water sector management, such as the development and implementation of river basin management plans and the Marine Strategy. Their function is to manage water, including mineral water, which is state property.

Basin directorates also have basic regulatory functions for issuing permits for water abstraction and use (Ministry of Environment and Water, 2025).

4.2. Analysis of the State of the Water Sector in Bulgaria.

The territory of Bulgaria is relatively well supplied with water resources, including surface and groundwater sources. Water sources are relatively evenly distributed in the country.

For the purposes of this study, a distinction should be made between the concepts of “Water abstraction” and “Water used”.

According to the National Statistical Institute of Bulgaria, “Water abstraction” is drawing water from any water source, permanently or temporarily. Abstracted waters are divided into fresh and non-fresh waters (marine and transitional). “Used water” is water that end users use for a specific purpose within a given territory, such as domestic purposes, irrigation, or industrial processing (National Statistical Institute, 2025).

The water abstraction for 2023 was 5,336 million m^3, with surface water being the primary source. Only approximately 10% of the water abstraction is from groundwater sources. The water withdrawn is mainly fresh (99.8 %), and the share of non-fresh water is insignificant. The largest share of water withdrawn is in the Danube region, which is 60% of the total water withdrawn in the country, followed by the East Aegean region, about 34%. It is impressive that the East Aegean region also has the most significant water losses of 450 million m3 per year.

Regarding economic activities, the largest consumer of water is the industry, particularly the production and distribution of electricity, heat, and gas, which accounts for approximately 80% of the total annual water usage. Fresh water withdrawn for hydroelectric power production (hydroelectric power plants) is approximately 18,000 million m3 per year, making it the largest consumer of fresh water, which, in most cases, is not reused.

Table 1. Water Used by Economic Activities and Type of Water Supply by Basin Management Areas (million m^3 per year, 2023).

Region	Danube	Black Sea	East Aegean	West Aegean
Agriculture, forestry and fisheries	25.92	7.29	282.81	4.79
Industry	2752.67	67.89	979.13	24.14
Services	21.80	19.61	20.54	11.03
Households	120.58	40.19	66.63	22.88
Water used by type of water supply – Public water supply	171.74	71.60	95.94	30.83
Water used by type of water supply – Own and other water supply	2749.22	63.39	1253.17	32.00
Water used – Total	2920.96	134.98	1349.11	62.83

Source: based on National Statistical Institute (2025).

The service sector has the lowest water consumption, accounting for less than 2% of the total water used.

From a territorial perspective, the Danube region accounts for the most significant amount of water used, approximately 65% of the total water used in the country. The East Aegean region follows, with approximately 30%. These regions also have the best water resources. Public water supply is not relied upon in these two regions, with over 90% of the water used coming from their own or other water supplies. The distribution between public and own water supply is approximately equal in the remaining two regions.

After industry, the largest consumer of water is households, with their share of drinking water usage being approximately 6% of the total water used.

Households primarily use water from public water supplies. A significant problem in Bulgaria is the considerable loss of water. Water losses, such as leaks and evaporation, are observed mainly during water transfer through the water supply network. Some of the water losses are registered as unauthorised consumption and measurement errors.

As shown in Figure 2, the water supplied and used by the public water supply and water losses have not changed significantly over the past 10 years. By 2023, the water supplied by the public water supply was 853 million cubic meters, of which the used water was 370 million cubic meters or less than 50%. Water loss represents an average of approximately 55% of the total amount of supplied water annually. From 2013 to 2023, water consumption and losses were relatively constant.

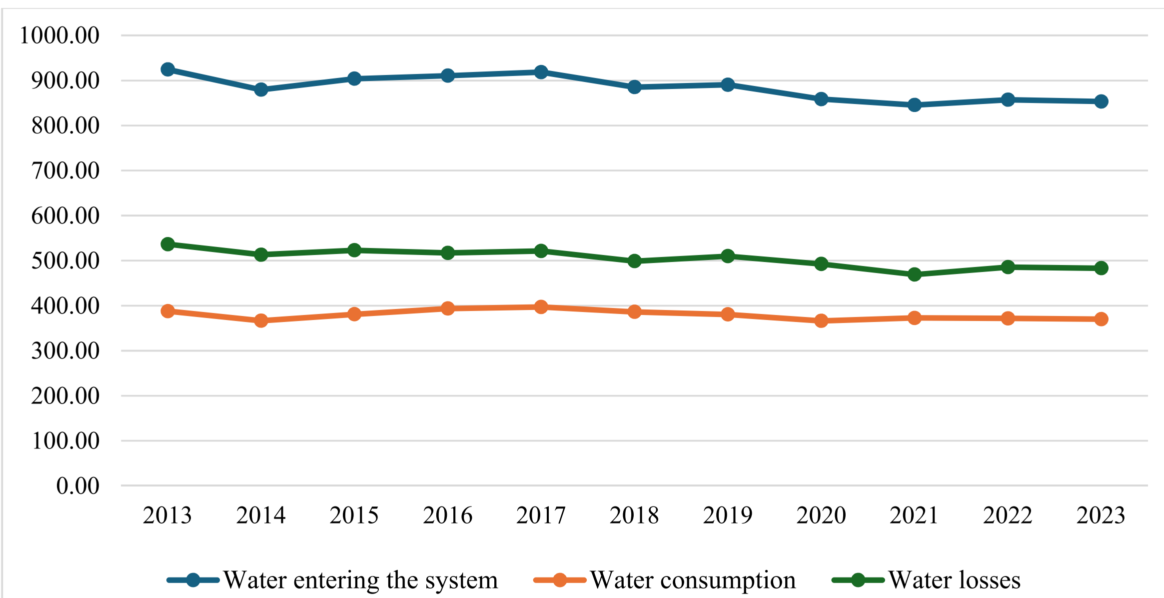

Fig. 2. Water distribution by Public Water Supply (Bulgaria, 2013-2023).
Source: based on National Statistical Institute (2025).

Table 2 presents data on the generated and discharged wastewater from the water basin management regions, excluding water from cooling processes.

The first column of the table shows the amount of water that, after use, leaves the place of use and is discharged into public sewerage and water bodies (National Statistical Institute, 2025). In territorial terms, the largest share of wastewater was in the Danube and East Aegean regions.

Households are the largest wastewater generators in Bulgaria, accounting for over 50% of wastewater. Much of the wastewater passes through treatment plants, at least with secondary treatment processes. The total number of treatment plants is 182, which are relatively well distributed across the regions, depending on their size. Much of the generated water is from cooling processes (3,404 million cubic meters/year), which is discharged mainly into water bodies.

Table 2. Wastewater Generated and Discharged by Water Basin Management Regions (Excluding Water from Cooling Processes), 2023.

	Million cubic meters/year				Number
	Wastewater generated - point sources	**Wastewater discharged into water bodies**	**Wastewater discharged without treatment**	**Wastewater discharged from treatment plants (municipal and other)**	**Operating municipal wastewater treatment plants**
Bulgaria	408,2	709,6	108,6	549,2	182
Danube region	158,8	291,6	30,7	238,6	61
Black Sea Region	63,4	113,2	4,6	101,9	40
East Aegean Region	152,9	248,0	55,5	175,0	57
West Aegean Region	33,0	56,9	17,7	33,6	24

Source: based on National Statistical Institute (2025).

A significant problem for the effective use of water resources is the loss of water in the water transmission network and the amount of water consumed/lost in the production of hydropower (HPP). As of 2023, Bulgaria has a 76,870 km water transmission network that is significantly outdated. The newly constructed water transmission network for 2019 – 2023 was only 409 km. During the same period, the reconstructed water transmission network was 2694 km.

The state of the sewage network is similar, as by 2023, the length of the sewage network is 13,193 km long. The newly constructed sewage network for 2019 – 2023 is 482 km, while the reconstructed one is only 109 km.

By 2023, 99.4% of the country's population was connected to the public water supply, with the Black Sea region having 100%. There are settlements with a water supply regime, which accounts for 4.5% of the country's population. The share of the population connected to treatment plants remains relatively small (67.4% of the population), and these are mainly small settlements (villages and small towns).

The same applies to the covered settlements and the population with public sewage; approximately 75% is connected to public sewage. Approximately 10% of the population is not connected to wastewater treatment plants.

Figure 3 shows the structure of expenses for the acquisition of environmental assets and long-term intangible environmental assets for 2013–2023, which gradually decreased, amounting to about 20% of the total expenditure on environmental purposes by 2023.

Compared to 2016, the share of costs was nearly 60% of the total costs for acquiring assets for environmental purposes.

Most of the costs of acquiring wastewater assets are for acquiring and constructing specialised facilities that do not participate in the production process and serve only to reduce pollution resulting from production. Nearly half of the costs of specialised facilities are for municipal wastewater treatment plants. Less than 1% of total costs go to pollution-control technologies.

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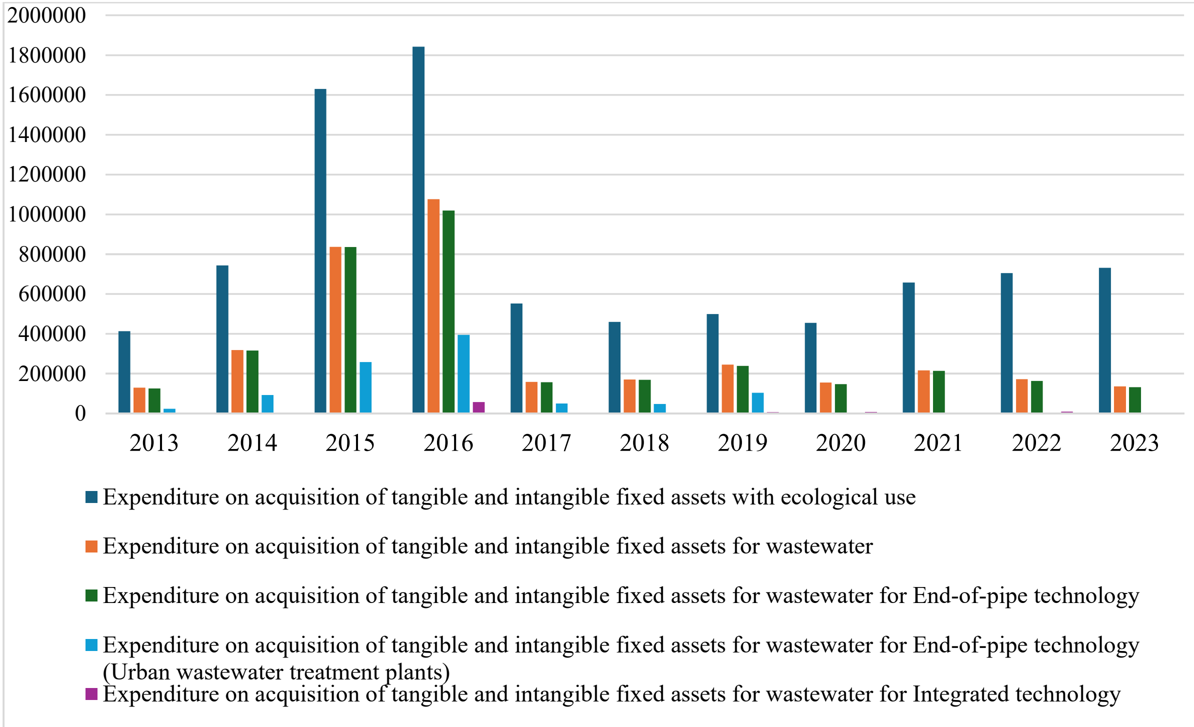

Fig. 3. Costs for Acquisition of Fixed Assets and Non-Current Assets with Environmental Purpose, 2013-2023 (thousands of BGN).

Source: based on National Statistical Institute (2025).

Figure 4 shows the structure of costs for environmental protection and restoration in general and for water resources protection and restoration.

In 2023, wastewater costs are approximately 15% of the total costs in the country for environmental protection and restoration.

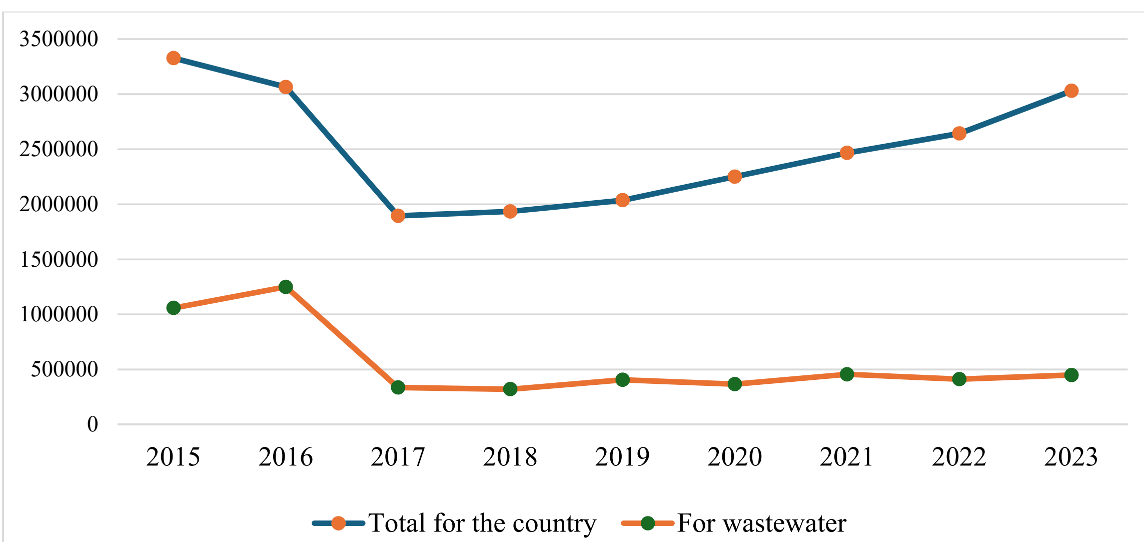

Fig. 4. Environmental Protection and Restoration Costs 2015 – 2023 (thousands of BGN).

Source: based on National Statistical Institute (2025).

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Overall, environmental expenditures are significantly small in this study. During the period under review, environmental protection and restoration expenditures increased, while water resource protection and restoration expenditures remained constant.

4.3. Water Used Efficiency Assessment.

The effective and resilient use of water resources must be consistent with the main influencing factors, such as economic, technical, social, and environmental factors. Resilient water resources management implies the development of a system of indicators for assessing the efficiency of water resource use, consistent with the factors and their influence.

4.3.1. Economic Criteria.

Assessment of the efficiency of water consumption and investments in water transmission infrastructure is carried out through the following indicators.

1. Productivity of water resources use:

$$P_w = \frac{Q_{pi}}{WC_i}$$

where: Q_{pi} – volume of production for region *i;*

WU_i – total volume of water used for region *i*.

2. Profitability of water use:

$$W_{prof} = \frac{R_i}{WU_i}$$

where: R_i – total revenue for a region *i*.

3. Assessment of investments in water transmission network:

$$I_{wsn} = \frac{IWSN_i}{I_i}$$

where: $IWSN_i$ – investments in water transmission network (water pipes and sewage networks) of region *i;*

I_i – investments in the region *i*.

4. Cost estimation for fixed assets:

$$C_{fa} = \frac{CFAww_i}{CFA_i}$$

where: $CFAww_i$ – expenses for fixed assets with environmental purpose for wastewater of region *i*;

CFA_i – total fixed assets costs of region *i*.

5. Estimation of costs for environmental protection and restoration:

$$C_{pre} = \frac{EPRCww_i}{EPRC_i}$$

where: $EPRCww_i$ – costs of environmental protection and restoration for wastewater of region *i*;

$EPRC_i$ – total cost of environmental protection and restoration of region *i*;

6. General indicator for assessing the economic efficiency of water use:

$$I_{eew} = \frac{1}{5}(P_w + W_{prof} + C_{fa} + C_{pre} + I_{wsn})$$

4.3.2. Technical Criteria.

Assessment of the condition of the water supply and sewage system is carried out through the following indicators.

1. Water supply network efficiency assessment:

$$E_{ws} = \frac{WE_i - WL_i}{WE_i} = \frac{WU_i}{WE_i}$$

where: WU_i – used water in region *i*;

WL_i – water loss in region *i*;

WE_i – water entering the system in region *i*.

2. Assessment of the efficiency of the sewerage network:

$$E_{wws} = \frac{WWC_i}{WWG_i}$$

where: WWC_i – wastewater collected to urban wastewater collecting system, including sewage treatment plants in region *i*;

WWG_i – total wastewater generated from region *i*;

3. Coverage of the territory (settlements) with water supply network:

$$S_{tp} = \frac{PWCs_i}{N_i}$$

where: $PWCs_i$ – settlements with water supply network in region *i*;

N_i – settlements in region *i*.

4. Coverage of the territory (settlements) with wastewater treatment plants and public sewage systems:

$$W_{wp} = \frac{WTPpop_i}{N_i}$$

where: $WTPs_i$ – settlements served by WWTP (Wastewater treatment) in region *i*.

5. General indicator for assessing the technical efficiency of water resource use:

$$I_{te} = \frac{1}{4}(E_{ws} + E_{wws} + W_{tp} + W_{wp})$$

4.3.3. Social Criteria.

The assessment of water supply and the efficiency of water consumption by the population is carried out using the following indicators.

1. Provision of drinking water to the population:

$$P_{wp} = \frac{N_i - Pwsr_i}{P_i} = \frac{Ppws_i}{P_i}$$

where: $Pwsr$ – population with water supply regime in region *i*;

$Ppws_i$ – population with continuous access to drinking water from the public water supply in region *i*;

P_i – population in region *i*.

2. Provision of the population with sewage:

$$P_{sewage} = \frac{Pwcs_i}{P_i}$$

where: $Pwcs_i$ – population connected to urban wastewater collecting system in region *i*;

3. Assessment of household water use efficiency:

$$WU_h = \frac{WEh_i - WL_i}{WEh_i} = \frac{WU_{h_i}}{WEh_i}$$

where: WEh_i – water entering to households from the public water supply in region *i*;

WL_i – water loss from public water supply in region *i*;

WUh_i – volume of water used by households in region *i*.

4. General indicator for assessing social efficiency of water resource use:

$$I_{se} = \frac{1}{3}(P_{wp} + P_{sewage} + WU_h)$$

4.3.4. Environmental Criteria.

Assessment of environmental impacts, wastewater treatment, and the reuse of water is carried out through the following indicators.

1. Evaluation of wastewater treatment efficiency:

$$T_r = \frac{TW_i}{WWD_i}$$

where: TW_i – treated wastewater in region *i*;

WWD_i – total wastewater discharged in region *i*.

2. Water reuse rate:

$$K_{reuse} = \frac{WRu_i}{WU_i}$$

where: WRu_i – volume of reused water in region *i*;

WU_i – total water used in region *i*.

3. Wastewater utilisation rate:

$$K_{ww} = \frac{WWRu_i}{WW_i}$$

where: $WWRu_i$ – volume of wastewater returned for reuse in region *i*;

WW_i – total volume of wastewater generated in region *i*.

4. Water footprint of the area:

$$WF_i = \frac{WU_i}{N_i}$$

5. General indicator for assessing the environmental efficiency of water resource use:

$$I_{ee} = \frac{1}{4}(T_r + K_{reuse} + K_{ww} + WF_i)$$

The overall assessment of the level of resilient management and use of water resources requires the derivation of a summary indicator, including the assessment of all factors in the model. The summary indicator includes weighting factors that consider the importance of each block for the overall assessment, depending on the territory in which it is applied. General indicator for assessing resilient use and management of water resources:

$$I_E = \omega(I_{eew} + I_{te} + I_{se} + I_{ee})$$

where: ω – weighting factor for the significance of the indicator; $\sum \omega = 1$.

An assessment scale was defined based on the summarised indicators to measure territorial differences and assess resilient water resource management.

Table 3. Scale for Assessing the Level of Resilient Management.

Indicator	Evaluation	Description
0,8 – 1	Very good	Very good level. There is no need to take drastic measures.
0,6 – 0,8	Good	Good level. Presence of problems that may arise in the future.
0,4 – 0,6	Satisfactory	Satisfactory level of management and efficient use of water resources. Additional measures are needed.
0,2 – 0,4	Poor	Low level of water resources management. Significant improvements are needed.
0 – 0,2	Very poor	Very low level of water resources management. The condition is critical.

Source: authors' development.

4.4. Implementation of a GIS Model for Resilient Water Resource Management.

Based on the derived indicators and their assessment, a model of territorial assessment of resilient management and use of water resources in Bulgaria was implemented.

Regional and municipal data were used to implement the model. The results of the GIS ArcGIS Online processing are presented in Figure 5. The assessment of the districts showed significant differences in the level of resilient management and use of water resources in Bulgaria.

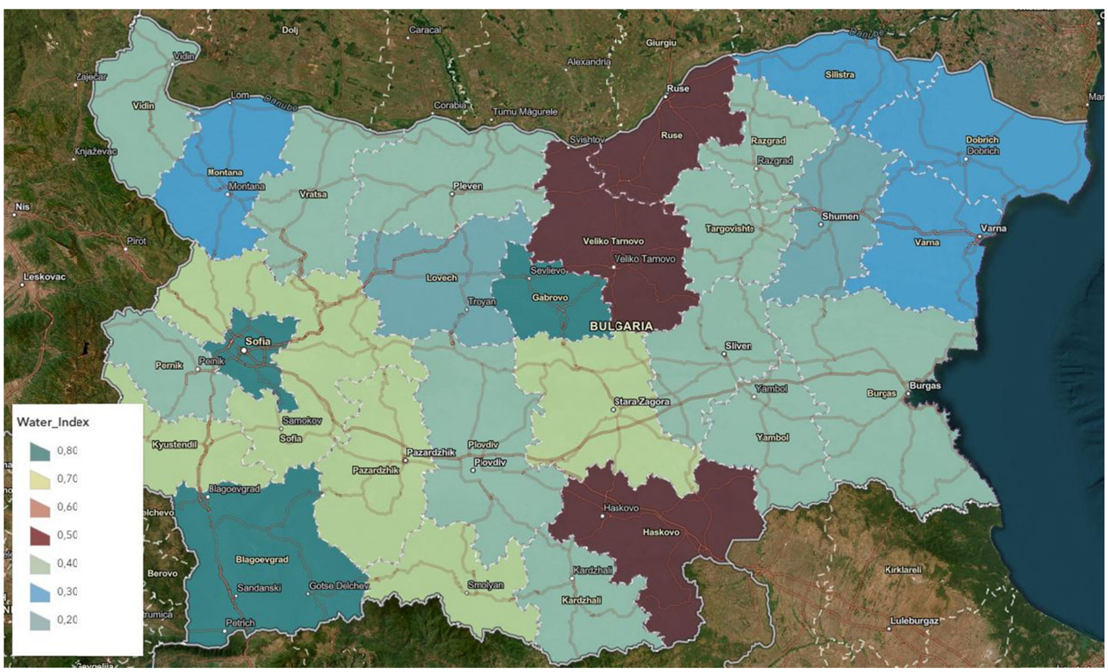

Fig. 5. Bulgarian Districts with Resilient Water Management Index Scores.

Source: based on ArcGIS Online.

Overall, according to the assessment, the condition of the territories is poor. No district in the country has a value in the “Very good” category (Fig. 5). The level is relatively low in Eastern Bulgaria and the Black Sea regions. High levels of water consumption characterise these territories.

At the same time, these territories have significant water losses in the water transmission network, with over 60% of the water supplied to the region. This situation is similar to that of the territories of Northwestern Bulgaria. The territories of the Northwestern region do not have high water consumption.

However, these territories also experience significant losses, approximately 60% of the water supplied. The districts of Shumen and Lovech had the lowest levels of the index for resilient management and efficient use of water resources. The central and southwestern parts of the country are relatively better. Most districts fall into the "Good" category in the range of 0.6 – 0.8.

These territories have high water consumption levels and lower water loss levels, approximately 50% of the supplied water. The districts with the highest index values were Sofia City, Gabrovo, and Blagoevgrad. However, the amount of water lost was significantly high. This represents a significant problem for resilient management and the efficient use of water resources.

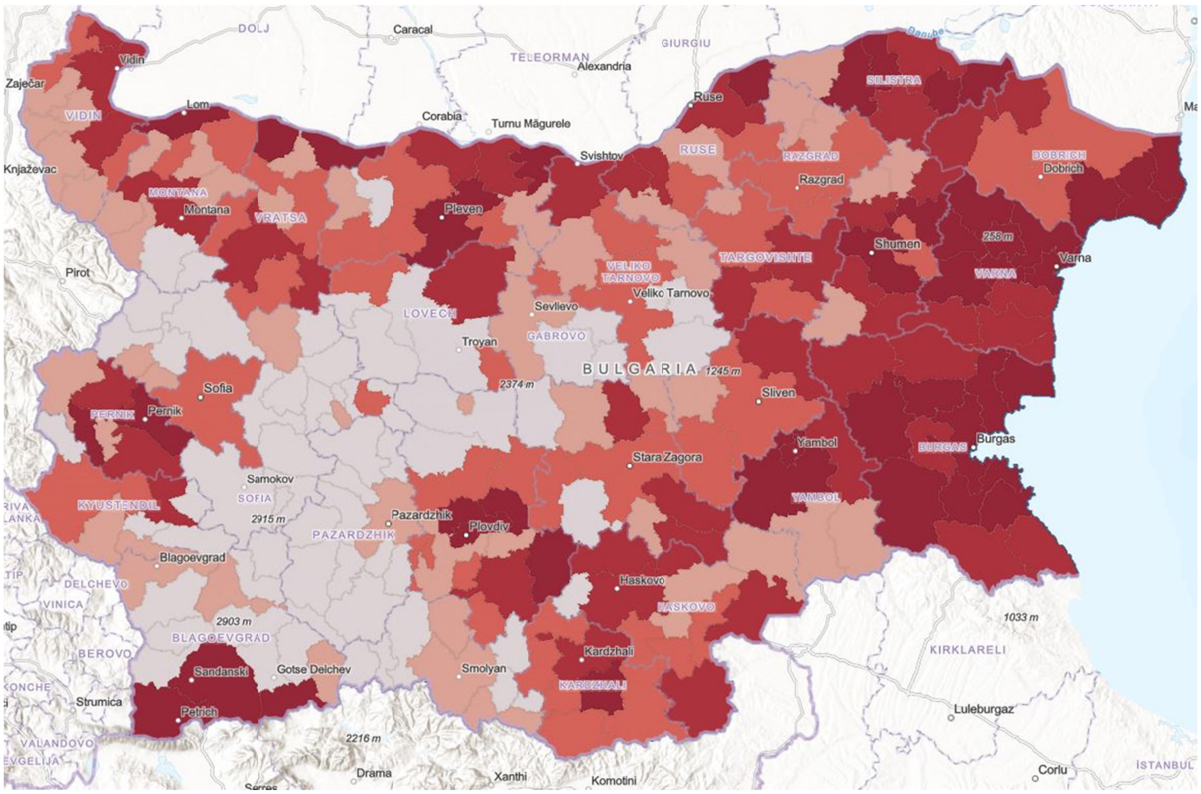

Fig. 6. Future State of Bulgarian Territories under Current Water Resource Trends (20-year projection).

Source: based on ArcGIS Online.

The map (Fig. 6) shows the state of the country's territory in 20 years, maintaining the current conditions. In general, the country's territory is at risk of water shortages. The red and dark red territories will be the most affected and may experience serious problems with the water supply.

This is dictated by several primary factors: climate change, population growth in large cities and depopulation of rural areas, large drinking water losses, and inefficient use of water resources, poor water supply and sewage infrastructure conditions, and the low level of wastewater reuse.

It is striking that these territories are at the mouths of rivers and water bodies, suggesting poor management of water bodies and inappropriate use of water resources. This requires developing an integrated management strategy and adopting drastic measures for the future development of the water sector in Bulgaria.

5. Conclusions.

Geographic information systems provide an opportunity to improve water resource management by integrating and processing large amounts of data.

This study examines the possibilities for improving management by developing and implementing GIS-based models to assess the state and simulate various scenarios of the water bodies. This study developed a model that integrates technical, economic, social, and environmental indicators for the resilient management and monitoring of water resources in Bulgaria. The proposed model can be used in water resource management. In response to the research questions, the current state of the water sector was analysed and assessed. The main factors affecting resilient management, the use of water resources, and territorial imbalances in the rational use of water were identified.

The proposed model provides a picture of the future state of the water sector and the consequences of the inefficient use and storage of water resources in Bulgaria.

This study contributes to the broader discussion on resilient water resource management. The question of achieving resilience in the sector remains open for future research

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