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GIS prognosis for nitrate pollution of shallow groundwater sources

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Abstract. An analysis of the quality of the supplied drinking water was conducted based on the nitrate indicator in the settlements of the Pleven administrative region. The district includes 123 towns and villages with a total population of 269,752 inhabitants (Census 2011). For public water supply, only groundwater extracted from the first aquifer is used. The region practices intensive agriculture, which necessitates the use of nitrogen fertilization. An analysis of the drinking water monitoring data from RHI and DRBD revealed that in eight settlements, the nitrate content was consistently high (above 50 mg/L). Spatial analyses were performed on two of the most nitrate-contaminated water sources (over 100 mg/L), which draw water from GWB with the following codes: No. BG1G0000QAL007 (Gigen and Iskar) and No. BG1G0000QAL017 (Koinare). The spatial analysis was carried out using GIS and the ArcGIS software package (ESRI). Several factors contributing to the maintenance of consistently high nitrate levels in groundwater were identified: the type of land use in the local watershed around the water source, the direction of drainage of the surface accumulation flows, the slope of the terrain surrounding the water source, and the general directions of groundwater drainage in the first aquifer. Specific proposals were made to achieve the standard for drinking water supplied to the population, including the following three options: mixing water from different points of GWB No. BG1G0000QAL007, changing the aquifer (GWB), or introducing an effective denitrification method (in the town of Koinare).

Key words: drinking water, groundwater bodies, nitrates, Geographic Information Systems.

Introduction

One of the main challenges underlying sustainable development is the need for better management of limited water resources (Elbeih, 2015). In Bulgaria, there is still a problem with the supply of quality drinking water according to the nitrate indicator, mainly in small villages. On one hand, freshwater reserves are decreasing, and on the other hand, water quality is deteriorating due to various sources of pollution, such as agriculture, industry, household waste, etc. In the early 1980s, the World Health Organization (WHO), in its report (WHO, 1984), identified four main sources of nitrates in surface and groundwater that pose a danger to human health:

1. Atmosphere – The contribution of the atmosphere is considered negligible, although some studies suggest it can account for up to 25% of the total nitrate load.

2. Agriculture – Agriculture is considered the main diffuse source of nitrates in natural waters worldwide. Nitrates are applied in large quantities as nitrogen fertilizers to feed crops, especially in areas with intensively developed agriculture.

3. Discharge of sewage and industrial wastewater into watercourses – This usually causes local problems in both ground and surface water, and is considered a "point source" of pollution.

4. Natural sources – Biodegradation of residual organic matter, mainly in agricultural lands, after harvesting.

In the same report, the WHO concludes that nitrates enter surface and groundwater from the soil in two main ways: through rainwater runoff and infiltration.

Runoff on the surface varies and depends on several factors, such as season, temperature, slope of the terrain, amount of precipitation, and type of cultivated crops. Infiltration in agricultural areas is greater towards groundwater, especially during the autumn and winter periods in fallow and arable lands with a compromised harvest (WHO, 1984).

Bulgaria is a country with well-developed agriculture and animal husbandry, both of which are major sources of water pollution with nitrates. This problem is characteristic of almost half of the administrative regions in the country, particularly those with intensive agricultural sectors, such as Pleven, Shumen, Targovishte, Dobrich, Silistra, Stara Zagora, and others (Vasilev et al., 2011).

Groundwater is used almost exclusively for water supply in the Pleven region. Groundwater is a natural water resource that is more difficult to control and monitor due to the specific characteristics of the Earth's subsoil (Nagarajan & Singh, 2009). According to the modern legislation of the European Union and Bulgaria, groundwater resources are defined as groundwater bodies (GWB) (Directive 2000/60/EC & Water Law, 2000). The measures regulated in European and Bulgarian legislation to reduce the nitrate load on natural waters often have limited results. Therefore, it is necessary to apply additional actions, such as replacing contaminated water sources or even aquifers, and, more recently, introducing innovative methods and technologies for denitrification of drinking water. In Bulgaria, there are still no methods or technologies implemented in practice for purifying drinking water from nitrates (Nikolov et al., 1992).

The present study aims to identify the groundwater bodies in the Pleven region in terms of their vulnerability to nitrate pollution from agricultural sources and to evaluate the possibilities for reducing nitrate concentrations in the supplied drinking water for public use, based on the specific conditions of the individual water supply systems.

Materials and methods

A retrospective study was conducted on data regarding the nitrate content in groundwater bodies in the Pleven region of Bulgaria for the period 2010–2017, based on monitoring by the Danube Region Basin Directorate (DRBD). The obtained data were processed statistically using Microsoft Excel 2010, and for each monitoring point, the mean and median nitrate content for the specified period was calculated.

The relative contribution of various factors to nitrate pollution, such as topography (slope and aspect) of the terrain, land use, and accumulation flows around the water sources, was assessed.

For this purpose, Geographic Information Systems (GIS) software products were used. GIS are also applied for hydrogeological mapping of groundwater resources in countries experiencing freshwater scarcity. By using remote sensing and GIS, potential water areas that could be used for extracting fresh drinking water can be identified (Choudhury et al., 2009; Ganapuram et al., 2009; Machiwal et al., 2011).

Spatial analysis of nitrate-contaminated water sources was performed using the ArcGIS software package, version 10.2.2 (ESRI), ArcMap module, and the Spatial Analyst extension. A watershed was modeled for each of the water sources to establish the expected direction of surface runoff (precipitation, irrigation, or wastewater). The modeling was based on a Digital Elevation Model (DEM) raster layer with a resolution of 20m.

The Watershed tool was used to model the accumulation and the direction of surface water outflow (accumulation flow). A slope raster layer, derived using ArcMap's Slope tool, was used for further analyses. After delineating the watershed, an area (buffer) with a radius of 100 m was defined around the water source, which was used to determine the terrain slope using the Extract by

Mask tool. From the resulting layer, statistics for the minimum, maximum, mean, and standard deviation (STD) of the slope in the buffer zone, as well as the range (the difference between the minimum and maximum values in degrees), were extracted using the Zonal Statistics tool.

For each catchment, the type of land use was also visualized using Corine Land Cover 2018. The percentage ratio of the different types of land use within the relevant catchment was also indicated, including non-irrigated arable land, pastures, vineyards, broad-leaved forest, fruit trees and forest plantations, water bodies, etc.

Results

In our previous studies, we discussed the towns and villages in the Pleven region with a permanent increase in the nitrate content in drinking water (over 50 mg/L) according to data from the monitoring of the Regional Health Inspectorate (RHI) (the town of Koinare and the villages of Gigen, Iskar, Gradina, Dragash Voivoda, Izgrev, Cherkovitsa, Zgalevo).

As groundwater is primarily used for drinking and domestic water supply, it is important to identify the groundwater bodies (GWBs) located in the Pleven region, as well as their qualitative and quantitative status.

According to the EU methodology for the determination of GWBs, they are classified into several groups. For the Pleven region, the 13 main GWBs can be grouped into the following five types:

1. GWBs in the Danube Lowlands (2 units):

- GWB No. BG1G0000QAL007 – Porous waters in the Quaternary – Karaboaz Lowland
- GWB No. BG1G0000QAL008 – Porous waters in the Quaternary – Belensko-Svishtovska Lowland

2. GWBs in the Alluvial Deposits of the Rivers Iskar, Vit, and Osam (right tributaries of the Danube) (3 units):

- GWB No. BG1G0000QAL017 – Porous waters in the Quaternary – Iskar River
- GWB No. BG1G0000QAL018 – Porous waters in the Quaternary – Vit River
- GWB No. BG1G0000QAL019 – Porous waters in the Quaternary – Osam River

3. GWBs in the Interriver Massifs in Northern Bulgaria, within the Pleven Administrative Region (4 units):

- GWB No. BG1G0000QPL023 – Porous waters in the Quaternary – between the Lom and Iskar Rivers
- GWB No. BG1G0000QPL024 – Porous waters in the Quaternary – between the Iskar and Vit Rivers
- GWB No. BG1G0000QPL025 – Porous waters in the Quaternary – between the Vit and Osam Rivers
- GWB No. BG1G0000QPL026 – Porous waters in the Quaternary – between the Osam and Yantra Rivers

4. GWBs in Typical Aquifers (2 units):

- GWB No. BG1G0000N1BP036 – Karst waters in the Lom-Pleven Depression
- GWB No. BG1G0000K2M047 – Karst waters in the Lom-Pleven Basin

5. GWBs Located in Karst Basins on Territories with Fissure Collectors (2 units):

- GWB No. BG1G0000K2S037 – Karst waters in the Fore-Balkans, along the Rivers Ogosta, Vit, Iskar, and Osam
- GWB No. BG1G0000K1040 – Karst waters in the Lovech-Tarnovo Massif, between the Rivers Vit, Osam, and Yantra

A thorough review of the database available in the DRBD showed that nine GWBs are vulnerable to surface pollution from agricultural sources, as they are located in the first aquifer. Even the karst GWBs, which in different areas appear as the second or third aquifer, are vulnerable in certain parts where they are exposed on the Earth's surface as the first aquifer (Fig. 1 and 2) (Danube Region Basin Directorate, 2010-2015).

Our analysis showed that, for the studied period, the most significant and persistent contamination with nitrates was found in the water sources of the villages of Gigen and Iskar and the town of Koinare (over 100 mg/L).

The tube wells in the village of Gigen are also used for water supply in the village of Iskar (approximately 4 km from Gigen) and draw water from GWB No. BG1G0000QAL007. The territory of this GWB covers an area of 222.1 km² and includes the descent along the right bank of the Danube River, limited to the west and east by the mouths of the Iskar and Vit Rivers, respectively (Fig. 1). The exposed area coincides with the total area of the GWB—i.e., the entire GWB is a primary aquifer. To the south, it extends several kilometers from the course of the Danube River. According to the typology of the National Institute of Meteorology and Hydrology (NIMH) for the characterization of GWBs, this water body is classified as a groundwater body in the Danube lowlands.

The geological structure is characterized by a substrate of sands, sandy-clay materials (Sarmatian), and mixed limestone-clay materials, on which alluvial layers from the river are deposited. The alluvial accumulations are formed in two layers: a lower gravelly-sandy layer and an upper clay-sandy layer. An aquifer is formed in the gravel-sand layer, the level of which reaches up to 5 m from the surface. The level of the aquifer changes depending on the water level in the river due to the presence of a direct hydraulic connection with the GWB. The movement of the accumulated water in the GWB is in the direction of the Danube River.

The interaction between the GWB and the other two smaller rivers is much weaker—the Iskar River in the west and the Vit River in the east. The water in the alluvial deposits of the GWB is mainly drained from the Danube River and is replenished by surface water infiltration from the Danube River and, to a lesser extent, from the geological substrate. The accumulated water in the GWB has a hardness in the range of 2.9-30 mg/eqv/L. The average thickness of the GWB is 20 m. The covering layers in the GWB feeding area are silty-sandy clay and deluvial-proluvial sediments. The natural resources of the GWB are estimated at 649 L/s, while the officially allowed water withdrawal quantity is 69 L/s (exploitation index - 11%).

The risk assessment regarding the quantitative status of Groundwater Body No. BG1G0000QAL007 indicates that it is not at risk. However, the risk assessment regarding its chemical status suggests that this GWB is at risk, with potential point and diffuse sources of pollution (agriculture and unsewered settlements) affecting its status. The degree of interaction of the GWB with surface waters is high, as there is a direct water exchange with the Danube River (Antonov, 1980; Danube Region Basin Directorate, 2010-2015). Groundwater Body No. BG1G0000QAL007 is also used for independent water supply to the villages of Brest, Zagrazhden, Kreta, and Somovit, as only the Brest and Gigen stations have an officially registered permit for water use in the DRBD (Danube Region Basin Directorate, Register). In each of the pumping stations for these independent water supply villages, the nitrate content is significantly below the norm (16-20 mg/L). The water supply amounts in these areas range from 50 to 390 m^3/day, and they are located at a distance of 10-30 km from the Gigen station (Regional Health Inspectorate, Monitoring Programme).

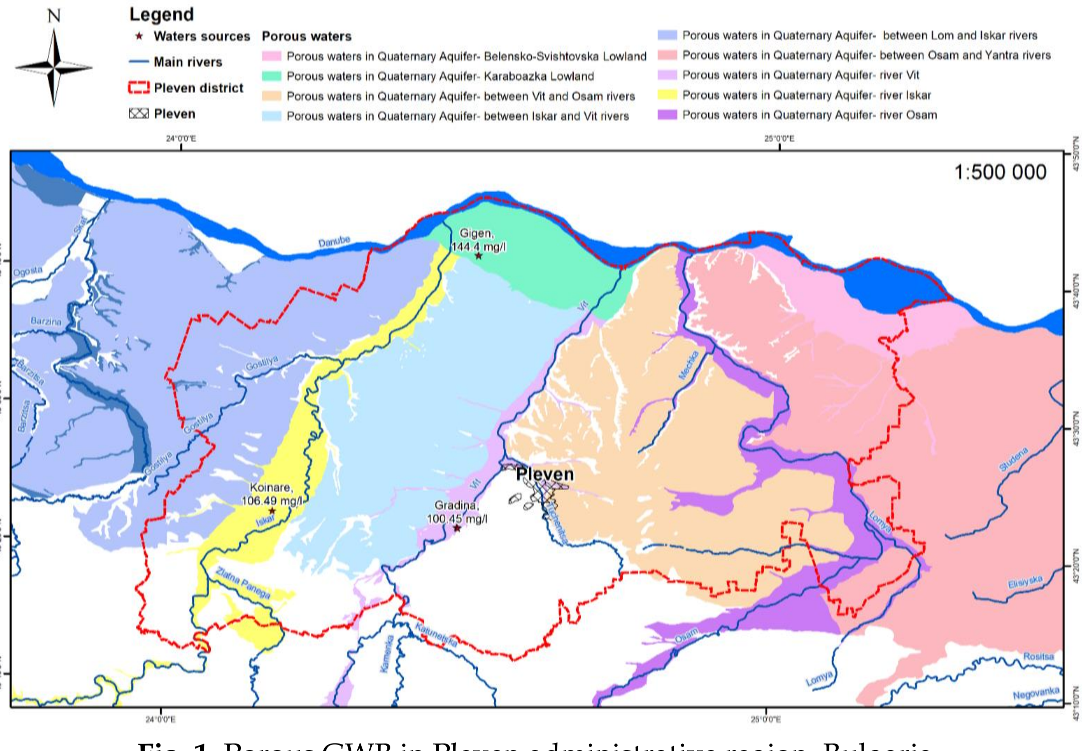

Fig. 1. Porous GWB in Pleven administrative region, Bulgaria.

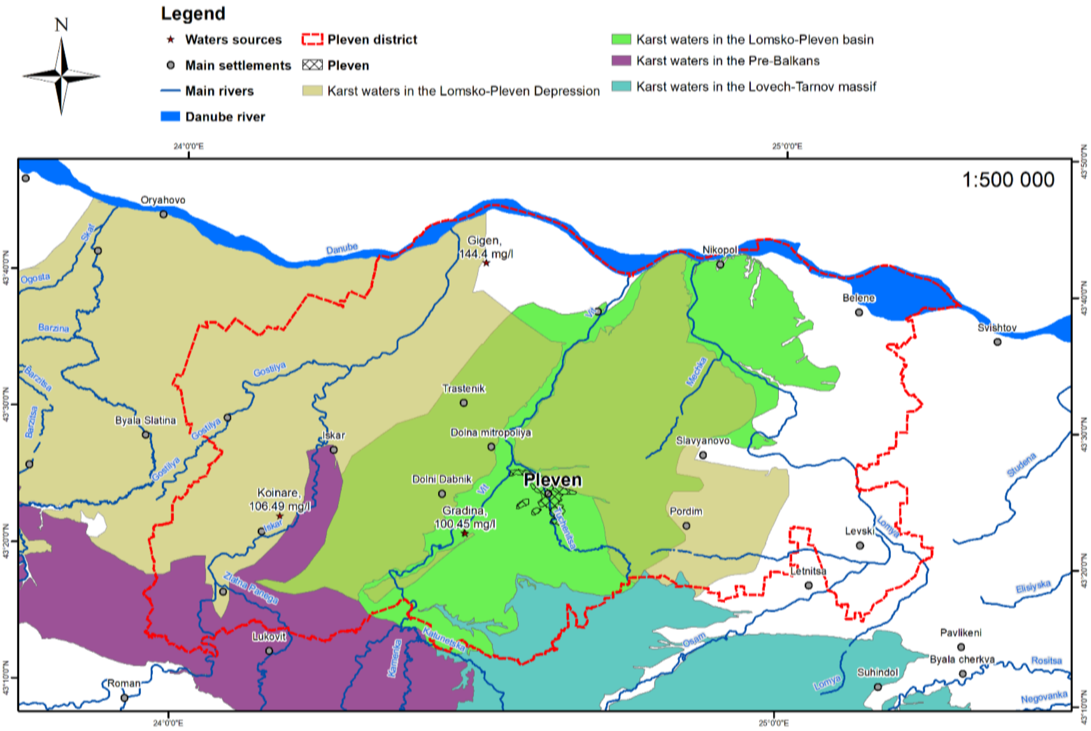

Fig. 2. Karst GWB in Pleven administrative region, Bulgaria.

In the land of the villages of Gigen and Iskar, there are also GWBs with codes BG1G0000QAL017 and BG1G0000QPL024. However, there is no information available in the DRBD about the depth of their aquifers in this area, nor data on the possible nitrate content from these GWBs taken from points located in the same territory. Organized water supplies exist in the upper course of the Iskar River, using boreholes from GWB BG1G0000QAL017 with standard nitrate values, but they are located at a very long distance from the village of Gigen. Therefore, it is practically impractical to explore opportunities for water supply to the village of Gigen from GWB BG1G0000QAL017.

The water source for the village of Gigen (4 tube wells) is located at the southeastern end of the village in a slightly shaped funnel. The buffer zone around the water source has a slight slope (mean = 3.22°, range 0 – 8.32°) (Table 2), directed inward toward the water source. This is a prerequisite for the collection of runoff water contaminated with nitrates (median for the period - 144.4 mg/L) from various sources to the wells, mainly from agricultural lands. The accumulation flow leaves the catchment area in a southeasterly direction through the lowest point in the topography of the watershed (the pour point), which is located 1267 m from the wells (Table 1).

Table 1. Distances of the water sources of the village of Gigen and the town of Koinare to the pour point.

Settlement	Municipality	Water source	median nitrate value [mg/L]	Distance to the pour point [m]
Gigen	Guliantsi	Tube well TW-1	144.4	1267
Gigen	Guliantsi	Tube well TW-2	144.4	1267
Gigen	Guliantsi	Tube well TW-9	144.4	1267
Gigen	Guliantsi	Tube well TW-10	144.4	1267
Koinare	Cherven bryag	Shaft well	106.49	116

Table 2. Slope within a 100-meter buffer around the water sources of the village of Gigen and the town of Koinare.

Settlement	Municipality	Water source	Slope in degrees				
			Min	Max	Range	Mean	Std
Gigen	Guliantsi	Tube well TW-1, 2, 9,10	0.00	8.32	8.32	3.22	1.65
Koinare	Cherven bryag	Shaft well	0.00	7.16	7.16	3.37	1.78

The modeled watershed around the water source for the village of Gigen covers an area of 3,426 ha.

Land use in the watershed includes the following types: "Non-irrigated arable land" - 84.6%, Broad-leaved forest - 6.22%, Discontinuous urban fabric - 3.21%, Transitional woodland-shrub - 2.12%, Complex cultivated patterns - 1.78%, Vineyards - 0.74%, Land principally occupied by agriculture, with significant areas of natural vegetation - 0.29% (Table 3).

Annual nitrogen fertilization is applied only to the lands in the catchment area classified as "Non-irrigated arable land", which represents 84.55% (2,896.7 ha) of the entire territory of the catchment (Fig. 3).

For the water source of the village of Gigen, a water protection zone (WPZ) has been established according to Regulation No. 3 (2000), with Zone III around the 4 tube wells covering an area of 1,302 decares and Zone II covering 432 decares. A ban has been placed on the application of nitrogen fertilization in Zone II of the WPZ, and limited application is recommended in Zone III, although the extent of the restriction has not been determined. The territory of Zones II and III is 100% occupied by agricultural lands, classified as Non-irrigated arable land (Corine Land Cover, 2018).

The city of Koinare is supplied with water from Groundwater Body No. BG1G0000QAL017 – Porous waters in the Quaternary - Iskar River. The GWB covers territories along the course of the Iskar River, from the villages of Gornik and Chomakovtsi to the confluence with the Danube River. The total area of the GWB is approximately 350.8 km². In the southern section of the GWB (Chomakovtsi village, Cherven Bryag municipality, Iskar town, and Dolni Lukovit village, Iskar municipality), the width of the river terrace is the largest, reaching 5-6 km, after which it narrows towards the mouth. This results in more abundant water reserves in these sections compared to the lower reaches of the river.

Table 3. Landcover in the watershed of the water sources for the village of Gigen and the town of Koinare.

	Watershed area [ha]		Watershed area [%]	
Land cover	**Gigen**	**Koinare**	**Gigen**	**Koinare**
Broad-leaved forest	213		6.22%	
Complex cultivation patterns	61	148	1.78%	2.87%
Discontinuous urban fabric	110	412	3.21%	7.97%
Fruit trees and berry plantations		0		0.01%
Industrial or commercial units		28		0.54%
Land principally occupied by agriculture, with significant areas of natural vegetation	10	49	0.29%	0.94%
Non-irrigated arable land	2897	3790	84.55%	73.25%
Pastures	37	163	1.08%	3.14%
Transitional woodland-shrub	73	132	2.12%	2.55%
Vineyards	25		0.74%	
Water bodies		452		8.74%
Total	3426	5174	**100.00%**	**100.00%**
Watershed perimeter [km]	33.89	67.89		

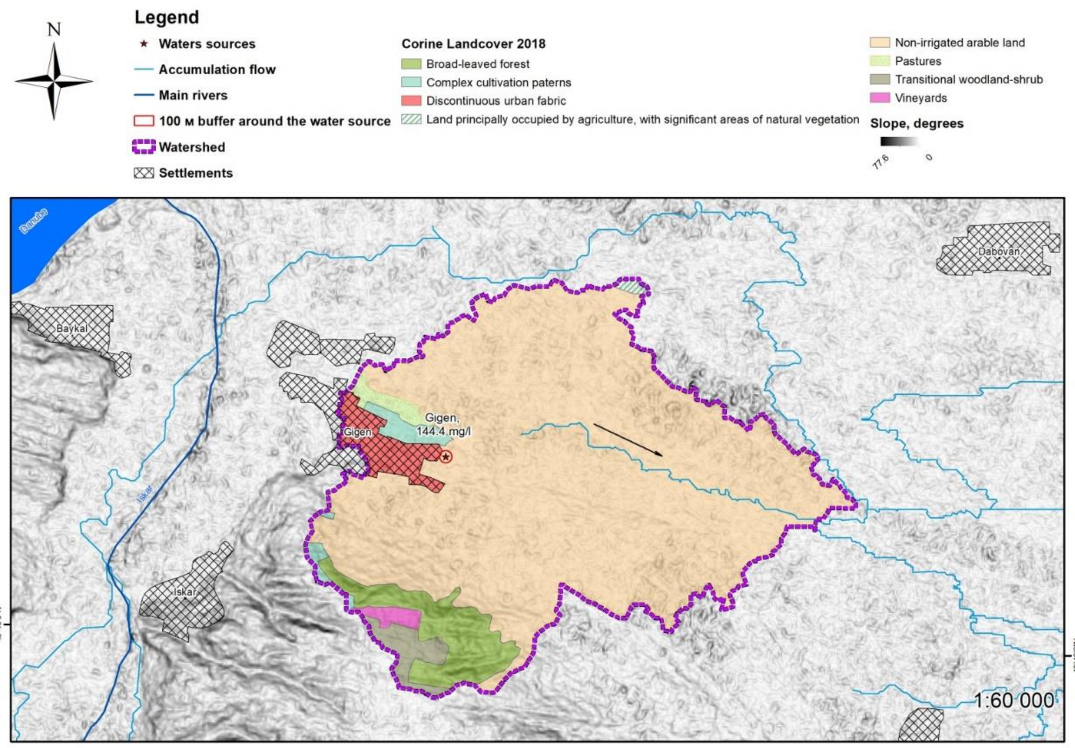

Fig. 3. Type of land use, accumulation flow, and direction of outflow at the water source of the village of Gigen, Bulgaria.

This GWB is classified as a groundwater body in the alluvial lowlands along the river terrace. The total area of the alluvial deposits in the river terrace has been estimated at 187 km² (DRBD, 2010-2015). The alluvial deposits in the lower layer consist of a gravelly-sandy layer at the bottom and an upper layer of clayey-sandy and sandy materials. Groundwater accumulates in the gravelly-sandy layer, which holds significant water reserves, particularly pronounced in the southern direction. The accumulated water is non-pressurized. The substrate on which the alluvial deposits accumulate consists of various materials, including limestones (Sennon), sandy clays (Sarmat), and clay-sandy limestones.

Nourishment of the groundwater is provided by precipitation falling on the surface of the terrace, groundwater from the underlying aquifers, and river water during high water levels of the Iskar River through hydraulic connections between the lower gravel-sand layer of the alluvium and the river waters. The water is fresh, with total mineralization below 1 g/L and total hardness ranging from 2.8-8 mg/eqv/L, which means it is medium hard to hard (Antonov, 1980).

The degree of interaction with surface waters is high, as there is a direct exchange with the Iskar River. The average thickness of this GWB is 9.5 m. The natural water resources amount to 1497 L/s, and the permitted water quantities are 163 L/s, which results in an exploitation index of 11%. This means that, quantitatively, GWB No. BG1G0000QAL017 is not at risk. However, its chemical status is threatened due to the presence of numerous diffuse and point sources of pollution (DRBD, 2010-2015).

Permits for water use from GWB No. BG1G0000QAL017 for drinking purposes have been issued by DRBD for the lands of the villages of Gornik, Lepitsa, Chomakovtsi, Glava, and the town of Koinare (all in the municipality of Cherven Bryag), the town of Iskar, along with Staroseltsi, Dolni Lukovit village (Iskar municipality), and Brenitsa village (Knezha municipality), as well as some settlements from Dolna Mitropolia municipality – Bregare, Gostilya, and Stavertsi villages (DRBD Register). Apart from Koinare, excessive nitrate content in drinking water has not been recorded in any of the above-mentioned settlements during the period.

For the town of Koinare, there is no officially established water protection zone around the water source by the order of the director of the DRBD, which complicates the imposition of prohibitions and restrictions related to nitrogen fertilization.

On the territory of Koinare town, there is also GWB No. BG1G000N1BP036, for which there is no available data on the depth of the aquifer in this area. A relatively short distance from the town of Koinare, there is a realized water supply for the town of Knezha from the same GWB, with standard nitrate values for the period of our research (median - 15.6 mg/L). Similar values for GWB No. BG1G000N1BP036 were recorded at sampling points in the village of Gramada (Vidin region) and the village of Doctor Yosifovo (Montana region), according to DRBD data.

The modeled watershed around the water source for the city of Koinare covers an area of 5174 ha (51,740 decares). Land use in the watershed includes the following types of land: Non-irrigated arable land - 73.3%, Water bodies - 8.74%, Discontinuous urban fabric - 7.97%, Pasture - 3.14%, Complex cultivated patterns - 2.87%, Transitional woodland-shrub - 2.55%, Land principally occupied by agriculture, with significant areas of natural vegetation - 0.94%, and others below 1% (Table 3, Fig. 4).

The spatial analysis of the territory around the water sources of Koinare town revealed a situation similar to that of the village of Gigen: a relatively weak slope in the buffer zone around the water source (χ = 3.37°; range 0 – 7.16°), and a distance of 116 m from the outlet (pour point) of the accumulation flow. For our research period (2010-2017), the median nitrate content in the water source of Koinare was 106.5 mg/L.

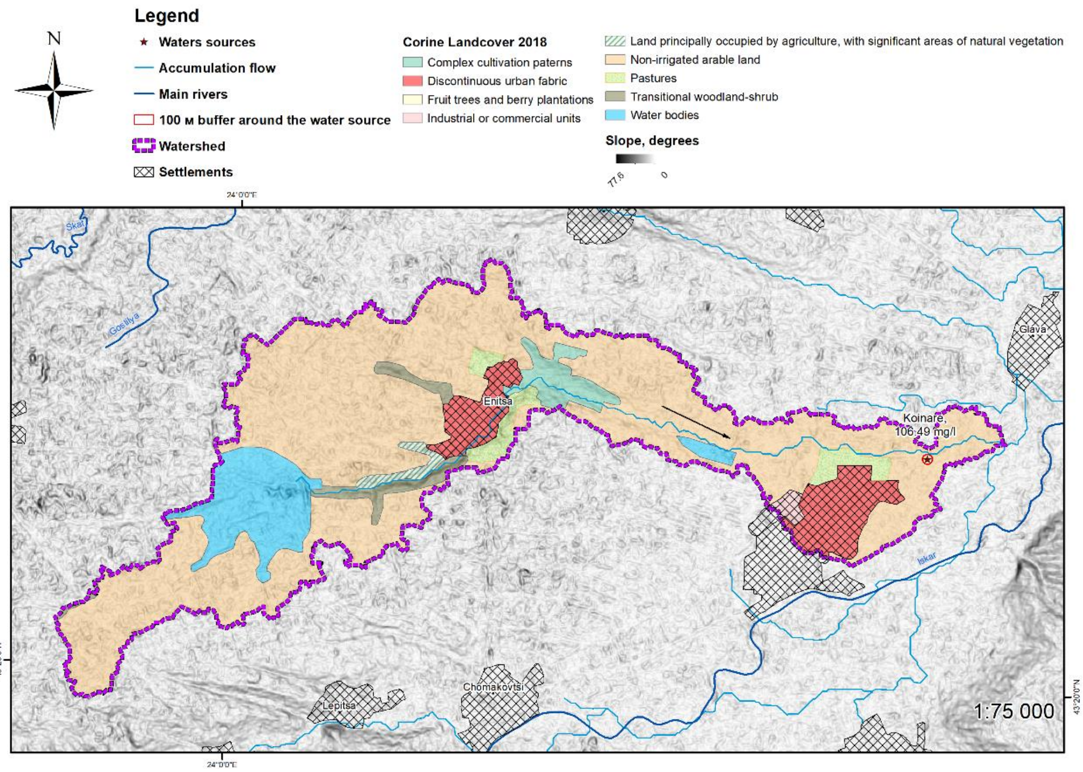

Fig. 4. Type of land use, accumulation flow, and direction of outflow at the water source of the town of Koinare, Bulgaria

Discussion

The manufacturer's recommended doses of nitrogen fertilizers (ammonium nitrate - NH_4NO_3) are in accordance with agrotechnical requirements and vary between 150-580 kg/ha, depending on the type of crop. The smallest amount is used for rapeseed, while the largest amount is used for irrigated corn. It is recommended that nitrogen fertilization be carried out in two stages: before sowing and during the vegetation period (in the spring season) (Table 4). The main question when discussing the restrictive measures for nitrogen fertilization around water sources concerns the dose of application. There is no consensus on the rate of plant uptake of nitrogen from artificial fertilizers. The prevailing belief is that absorption varies between 50 to 70-75% of the administered dose (Stoichev et al., 1996).

Table 4. Manufacturer's instructions for professional use of ammonium nitrate.

№	Agricultural crop	Quantity norm for ammonium nitrate, kg/ha	Implementation period
1	Wheat	230-410	1/3 before sowing 2/3 during vegetation
2	Barley Winter brewery	 230-410 170-260	 1/3 before sowing 2/3 during vegetation
3	Corn irrigated unirrigated	 490-580 260-400	 2/3 before sowing 1/3 during vegetation
4	Sunflower	200-260	2/3 before sowing 1/3 during vegetation
5	Rapeseed	150-200	2/3 in the autumn 1/3 in the spring (or 3/3 in the spring)

The Danube hilly plain occupies the territory between the Balkan Mountains, whose terrain reaches over 2000 meters above sea level, and the Danube River to the north. In general, the slope of the plain is from south to north and from west to east until the Danube River empties into the Black Sea. The Pleven administrative district occupies a territory in the middle part of the Danube Plain. According to hydro-geological studies, the migration of groundwater in the Danube Plain occurs in a south-north direction and from west to east (Antonov, 1980). All the main rivers cross the plain from south to north until they empty into the Danube River, except for a few rivers in the Eastern Balkan Mountains that flow into the Black Sea. Groundwater bodies (GWBs) located in the interfluves of the Rivers Iskar, Vit, and Osam, during their movement from west to east, are also drained to the banks of the mentioned rivers.

The current practice for sizing Water Protection Zones (WPZs) is based on hydrogeological studies of the probability of attracting a certain pollutant to the site of groundwater capture during the exploitation of the water source. However, in the case of nitrates, the situation is likely different. Nitrates are a permanent element in soils, with practically unlimited solubility in water. Complex balances between soluble and insoluble constituents are maintained in the soil complex, depending on the impact of multiple factors, often acting in opposite directions. In practice, situations are often observed where, even after restrictions and prohibitions on artificial fertilization, the concentration of nitrates in extracted drinking water does not change significantly. This raises doubts about the effectiveness of the recommended restrictions on nitrogen fertilization.

The officially established WPZ around the water source for the village of Gigen is sized with an area for Zone III of 1302 decares and Zone II of 432 decares, which represents a significantly smaller area than the territory of the watershed modeled with the help of GIS around the same water source. Cultivable land subject to nitrogen fertilization in the watershed area is 28,970 decares (84.55% of the total area of the watershed) (Table 3, Fig. 3).

A Water Protection Zone (WPZ) has not been established around the water source of Koinare town, despite the water source having existed and operated continuously for about 50 years. No nitrogen fertilization restrictions are known to have been applied around the water source.

The water source for the town of Koinare is located between the settlement and the pour point, which increases the potential for additional contamination of the groundwater body with wastewater generated by the town. This indicates that the contamination of the water source for Koinare is primarily due to the hydrogeological features of the area.

The main factors contributing to and maintaining the permanently high nitrate values in the water sources include:

- The large area of the local surface water catchment around the water sources;
- The direction of movement of the water masses in the accumulation flow, determined by the relief of the earth's surface toward the wells;
- The gentle slope in the buffer zone immediately around the water sources;
- The proven direction of drainage of the waters from the first water-bearing horizon, flowing from south to north and from west to east.

All these factors, objectively proven by the spatial analyses and hydrogeological studies (Antonov, 1980), cumulatively influence the increase in nitrate concentration in the groundwater of the first aquifer captured by the two water sources. In addition to these factors, the influence of the soil cover in the groundwater bodies (alluvial soils in the riverside terraces of the Danube and Iskar Rivers) should also be considered. This soil cover is characterized by a well-defined fine structure, very good water permeability, and excellent filtration qualities—properties that favor the migration of nitrate ions during the filtration process of surface waters (primarily precipitation) feeding the first aquifer.

Given the results obtained from the study, and in order to achieve the main goals set in European and Bulgarian normative documents for the supply of water with low nitrate content (below 50 mg/L) to the villages of Gigen and Iskar, the most favorable solution could be achieved by mixing the water from the contaminated water source with water extracted from the same groundwater body at the pumping stations for nearby settlements - Brest, Zagrazhden, Kreta, and Somovit. For this purpose, only the construction of a pipeline connection is necessary. The cost of this solution would need to be determined through a specialized technical and economic analysis.

We believe that the low concentrations of nitrates in the water sources located near the Danube River, which supply the aforementioned Danube settlements, will be preserved even if the operational flow rate increases in order to mix with the water from the water source for the village of Gigen. The risk of an increase in nitrate content in the water sources with consistently low nitrate values is minimal because these low concentrations are primarily due to the powerful influence of the existing direct hydraulic connection between the groundwater body and the waters of the Danube River, a characteristic generally found in flowing surface waters (rivers, lakes). According to data from quarterly reports of the Environmental Executive Agency, the nitrate nitrogen ($N\text{-}NO_3$) levels along the Danube River, in the part passing through Bulgaria, as well as along the Iskar River, have not exceeded 2 mg/L over the last decade (Environmental Executive Agency, 2011-2021).

The water source for the town of Koinare is permanently contaminated with nitrates, with a concentration exceeding 100 mg/L. At close distances, no other drinking water sources have been developed from the same groundwater body. There is only one other groundwater body in the Koinare area (No. BG1G000N1BP036 – Karst waters in the Lomsko-Pleven depression), but there is no available data on the qualitative (nitrate content) and quantitative indicators for this GWB in the territory of Koinare town. Since the town has the largest population exposed to elevated nitrate levels in drinking water in the Pleven region (over 3000 inhabitants), we consider it appropriate to discuss the possibility of implementing an effective technology for denitrification of drinking water. Such technologies have already been developed and implemented in France, Germany, England, and the USA (Mateju et al., 1992).

Conclusions

In conclusion, to solve the main issue related to a real reduction of the concentration of nitrates in the drinking water supplied to the population of the village of Gigen, the village of Iskar, and the town of Koinare, we offer the following recommendations:

1. Mixing in certain proportions of water from the functioning water source of the village of Gigen and some of the nearby water sources with low concentrations of nitrates, used for water supply to the villages of Brest, Zagrazhden, Kreta, and Somovit, fed by the same GWB.

2. For the town of Koinare, we offer an alternative solution: in the presence of reliable hydro-

geological data for quantitative (guaranteed sufficient operational water volume) and qualitative indicators (nitrates below 50 mg/L) in GWB No. BG1G000N1BP036, presented in the land of the town, measures can be taken for the construction of a new water source on this GWB. If, as a result of the relevant professional (technical and hydrological) analysis, it turns out that this proposal is not expedient, the possibility of applying a sufficiently effective method of denitrification of the water of the current water source could be discussed.

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