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DEPARTMENT OF HYGIENE, MEDICAL ECOLOGY, OCCUPATIONAL DISEASES AND DISASTER MEDICINE

“ NITRATE CONTENT IN THE DRINKING WATER OF THE PLEVEN REGION AND POSSIBLE APPROACHES FOR THEIR REDUCTION“

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ABSTRACT OF A DISSERTATION

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The materials on the defense are available in the scientific department of MU-Pleven and published on the website of MU-Pleven.

Note: The numbers of the figures and tables in the absract do not correspond to those in the dissertation

CONTENTS

Abbreviations used

DEM – Digital elevation model

DRBD – Danube Region Basin Directorate

DWW – Domestic waste water

ESRI – Environmental Systems Research Institute

GPS – Global Positioning System

GWB – Ground water body

KW – Karst wells

NSI – National Statistical Institute

PS – Pump station

RHI – Regional health inspectorate

RBMP – River Basin Management Plan

ShW – Shaft well

SD – Standard deviation

TW – Tube well

W&S – Water and Sanitation

WPZ – Water protection zone

WSG – Water suplly group

WWTP – Waste water treatment plant

INTRODUCTION

Water is of a great biological importance - it is a living environment, participates in the structural elements of the body, plays an essential role in the processes of thermoregulation and maintaining the water-electrolyte balance.

Water is also vitally necessary to satisfy the drinking, communal, household and economic needs of the population.

Nowadays, finding suitable water sources with sufficient flow rate and satisfying health requirements is becoming an increasingly urgent problem.

The quality and composition of water are extremely important for the spread of some infectious and non-infectious diseases.

Contamination of drinking water with nitrates is a very telling example of pollution of anthropogenic origin, as a result of the mass use of nitrogen fertilizers in agriculture.

The content of nitrates in drinking water is a parameter related to human health, which obliges EU member states to carry out the corrective actions in accordance with european and national regulatory documents.

The most vulnerable is the group of children under the age of 1 year (methemoglobinemia), but there are many scientific studies, both by our and foreign scientists, which prove that other disorders in the human body are associated with increased nitrate content - gastrointestinal disorders, stimulation of the iodine deficiency in pregnant women and children of school age, and carcinogenic processes are not excluded.

Despite the introduction of strict legislative measures at european and national level, nitrate contamination of waters still exists and in many places the trend has not even turned towards reducing pollution.

Reducing the content of nitrates in drinking water is not an easily achievable task in a short period of time - the implemented programs of measures to limit and prevent pollution with nitrates from agricultural sources are revised every 4 years.

In the last 2 decades, significant progress has been made in the application of new approaches to solving the problem of nitrate content in drinking water:

– creation and implementation in practice of new methods and technologies for denitrification of nitrate-contaminated groundwater;

– use of Geographic Information Systems (GIS) for spatial modeling in the evaluation and selection of reliable and promising water sources.

I. AIM AND TASKS

The aim of the present work is to study the nitrate content in the drinking water of the settlements in the Pleven region and the possible approaches for their reduction.

To achieve this goal, we have set ourselves the following **tasks:**

1. To collect information on the content of nitrates in drinking water for public use in the Pleven region for the period 2010-2017.

2. To identify and prioritize the most heavily nitrate contaminated water supply areas in the Pleven region.

3. To gather information about the ground water sources in the region containing excessive nitrate values (over 50 mg/L) and to assess the state of the sanitary protection zones around them.

4. To assess the effectiveness of the currently effective regulative documents for reducing the nitrate load of groundwater used for water supply to the population.

5. To characterize the ground water bodies in the Pleven region, used for the extraction of drinking water, in view of their vulnerability to nitrate pollution from agricultural sources.

6. To recommend the most effective approaches for reducing the nitrate content in the most heavily contaminated water supply areas.

III. MATERIALS AND METHODS:

1. Subject of the study.

The subject of this dissertation is the content of nitrates in the drinking water of the Pleven region and an assessment of the possibilities for their reduction.

2. Object of the study.

The object of our research is drinking water in the Pleven region.

3. Design and methodology of the study

In order to achieve the goal, we divided the performance of the tasks into the following research stages, in which we used different methods (Table 1):

Table 1 – Stages and methods used in the study

Stages	Description of the stage	Methods used in the study
Stage 1	Identification of the most nitrate-contaminated water supply areas by collecting and analyzing the results for the content of nitrates in the drinking water of the Pleven region for the period 2010-2017.	-retrospective study of the data on the content of nitrates in the drinking water of the Pleven region according to the Drinking Water Quality Monitoring Program of the RHI-Pleven; - statistical processing by averaging the data and grouping them by years and seasons
Stage 2	Study on the presence and condition of Water protection zones (WPZs) around water sources containing excessive nitrate values (over 50 mg/L) for the same period	- individual interview method; -documentary study of the Danube Region Basin Directorate (DRBD) registers, containing the permits for water use and information on the established WPZs in the district.
Stage 3	Identification of Ground water bodies (GWBs) used for extraction of drinking water in Pleven region	- documentary study of information from the DRBD, included in the River Basin Management Plan (RBMP) 2010-2015 and RBMP 2016-2021; - visualization of the GWBs through maps generated in a GIS environment and the MapViewer tool
Stage 4	Analyzing the results of the planned monitoring of the GWBs carried out by the DRBD according to the nitrate indicator for the period 2010-2017	-retrospective documentary study of the data on nitrate content in the water of the GWBs, located in the management area of the DRBD; -статистическа обработка на данните с Microsoft Excel 2010, чрез осредняване и намиране на медиана
Stage 5	Collecting data on the amount of precipitation in the Pleven region for the period 2010-2017 and	1. Retrospective study of the data on the amount of precipitation in the area, located in National Institute of Meteorology and

	performing a comparative analysis between the content of nitrates in water sources, which showed permanently excessive values, and the amount of precipitation on a monthly, seasonal and annual basis.	Hydrology (NIMH)-Pleven and statistical processing of the data using IBM SPSS Statistics 20; 2. Comparative analysis of the data on nitrate content in drinking water and the amount of precipitation by using the following methods: - Calculation of statistical characteristics of the central tendency; - Calculation of statistical characteristics of dispersion - Standard deviation; -Methods for statistical testing of hypotheses - Kolmogorov-Smirnov test; Kruskal-Wallis method (comparative statistics); Graphical analysis; -Dependency methods-correlation analysis, regression analysis.
Stage 6	Analysis of the specific causes of nitrate pollution of water sources (relief, land use, direction of accumulation flows in the relevant watershed, etc.) by using Geographical Information Systems (GIS).	The following GIS tools were used: -ArcGIS Living Atlas; -ArcGIS, version 10.2.2 (ESRI) – ArcMap module, the Spatial analyst extension; -Digital Elevation Model and ArcMap's Slope tool; - Watershed tool; -Zonal Statistics; -Corinne Land Cover 2018

RESULTS

1. Water resources and public water supply in the Pleven region - settlements, water supply areas, types of water sources and nitrate content in drinking water.

The district of Pleven is located in the Danube hilly plain, extending to the north to the Danube river. It occupies an area of 4653.3 km², on which 123 settlements (14 towns and 109 villages) are located, distributed in 11 municipalities - Belene, Gulyantsi, Dolna Mitropolia, Dolni Dabnik, Iskar, Knezha, Levski, Nikopol, Pleven, Pordim, Cherven bryag. Administratively, the district borders with Lovech district - to the south, Vratsa district - to the west and Veliko Tarnovo district - to the east.

According to the data of the National Statistical Institute (NSI), a total of 269,752 inhabitants live in the Pleven region, of which - 171,821 in the cities and 97931 - in the villages.

In addition to the GWBs, the three large rivers located on its territory - the Iskar River, the Vit River and the Osam River, as well as the Danube River - are of significant importance for the water resources in the district.

For drinking and domestic water supply of the settlements in the district, ground water sources are mainly used, capturing water from the first aquifer, which accumulating rainwater filtered through the soil.

Water supply is organized in 105 water supply zones. Ninety of the zones supplying water to only 1 settlement, and 15 of them are group water suppliing systems (they supply water to more than 1 settlement), i.e. independent water supply systems were built for almost every settlement, including water sources located in the lands of the settlements outside the urbanized territories. Long water pipelines are an exception for the district and were built to bring water to the relevant settlement from the surface water sources, which are characteristic of only 2 of the water supply zones - zone No. 9 (Cherni osam group) and zone No. 10 (Zlatna Panega group). Zone No. 9 supplies water to part of the city of Pleven and the villages: Bohot, Brestovets, Kashin, Laskar, Nikolaevo, Ralevo, Todorovo, and Zone No. 10 supplies water to the city of Cherven Bryag (Table 2).

Table 2 – Type and number of water supply zones in Pleven region

water supply zone	Number of the zones
Large - with a volume of distributed water over 1000 m^3 and/or with a permanent resident population over 5000 people	12
Small - with a volume of distributed water below 1000 m^3 and/or with a permanent population below 5000 people	93
Total	105
independent water supply	90
group water supply	15
Total	105

After a detailed review and processing of the data on the content of nitrates in the drinking water of the settlements in the Pleven region, the settlements with permanently excessive values for the period, as well as those with a standard content of nitrates, were determined.

There are 8 settlements in the Pleven region supplied with drinking water containing persistently high nitrate values for the period 2010-2017, organized into 8 small water supply zones (Table 3). In 2 of the zones that supplying water to three of the eight settlements, the average concentration of nitrates for the period is permanently above 100 mg/l - the village of Gigen and the village of Iskar, Gulyantsi municipality (150.68 mg/L) and the town of Koynare, municipality Cherven bryag (106.24 mg/L). In the remaining 5 settlements, the average concentrations vary between 50.61 mg/L and 95.34 mg/L (the villages of Zgalevo, Cherkovitsa, Izgrev, Dragash voivoda and Gradina) (Table 3). In the remaining 8 zones, supplying water to 9 villages, excessive nitrate values (> 50 mg/L) were recorded in separate months and years, but the average values for the period were between 35 and 50 mg/L (the villages of Pelishat, Tuchenitsa, Radishevo, Borislav, Obnova, Bozhuritsa, Petarnitsa, Gortalovo and Gornik) (Table 3).

The relative share of those exposed to permanently excessive nitrate values for the studied period (above 50 mg/L) is 8,617 inhabitants, which represents 3.2% of the total population of the district. The most vulnerable group (children in infancy) is 0.1% of the population in the district.

Table 3 - Settlements in the Pleven region with high levels of nitrates in drinking water for the period 2010-2017 and data on the number of the exposed population

№	Settlements	Municipality	Nitrate content, mean value [mg/L]	Population-number	Number of the population up to 1 year old
1.	v. Gigen,v.Iskar	Gulyantsi	150,68	2270	22
2.	Town Koynare	Cherven bryag	106,24	3706	92
3.	v.Gradina	Dolni Dabnik	95,34	486	13
4.	v.Dragash voivoda	Nikopol	76,65	573	9
5.	v.Izgrev	Levski	61,33	430	3
6.	v.Cherkovitsa	Nikopol	61,27	466	6
7.	v.Zgalevo	Pordim	50,61	686	6
8.	v.Pelishat	Pleven	49,13	648	10
9.	v.Tuchenitsa,v.Radishevo	Pleven	46,48	877	8
10.	v.Borislav	Pordim	43,53	183	4
11.	v.Obnova	Levski	42,99	1990	36
12.	v.Bozhuritsa	D.Mitropolia	42,92	992	26
13.	v.Petarnica	Dolni Dabnik	42,80	1533	53
14.	v. Gortalovo	Pleven	37,94	154	3
15.	v.Gornik	Cherven bryag	36,56	1064	50
Ttotal				16 058	341

2. Presence of WPZs around water sources with permanently high levels of nitrates in drinking water.

After establishing the most nitrate-contaminated water sources in the district, together with representatives of RHI-Pleven and "Water & Sanitation " Ltd. - Pleven, a site visit was carried out. The technicians representing the operating company provided basic information about the water sources - flow rate, depth, type of water catchment facilities. A documentary study was also carried out in the official registers of the Danube Region Basin Directorate, containing the permits for water use for drinking purposes, as well as information on the established WPZs, according to the requirements of the current Regulation No. 3 on WPZs.

According to the officially published information on the DRBD website (which is periodically updated), only one of the water sources of the 17 villages listed above (Table 3) has an established WPZs, according to the requirements of the current Regulation No. 3, and this is the water source for the villages of Gigen and Iskar.

According to information from RHI-Pleven, about 500 water sources are used for drinking and domestic purposes on the territory of the Pleven region, and according to the DRBD register, only 66 of them have officially established by order of the Director of the DRBD - WPZs, i.e. 13% of all settlements in the district (Fig. 1). Of these 66 WPZs, 42 are for water sources supplying the city of Pleven, 2 are for the city of Knezha, 4 for the city of

Nikopol, 2 for the village of Lazarovo, 2 for the town of Slavyanovo, and the remaining 14 are for water sources of 10 settlements in the district. Out of 123 settlements in the Pleven region, only 16 settlements have WPZs around the water sources established by order of the Minister.

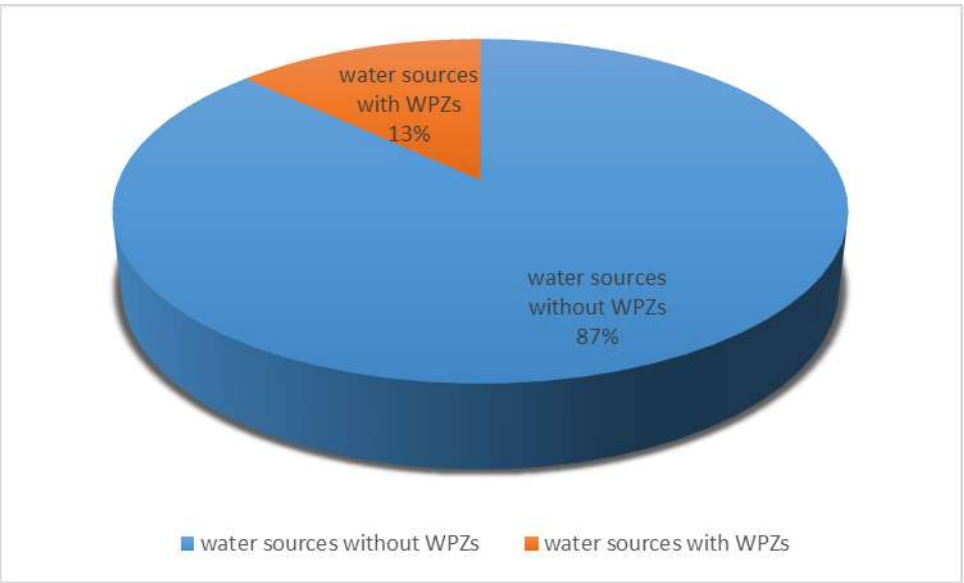

Figure 1 – Relative share of water sources in the Pleven region with WPZs compared to those without WPZs

3. Ground water bodies in the Pleven region - characteristics, nitrate content for the period 2010-2017.

The qualitative and quantitative characterization of groundwater allows to assess the extent of its contamination and provides information for better management of groundwater resources.

According to the current legislation in the European Union and Bulgaria, ground water resources are described as ground water bodies. 13 GWB's are mainly used for water supply to the settlements in Pleven region. According to Order No. 930/25.10.2010 of the Minister of the Environment and Waters for the determination of nitrate-vulnerable zones, 9 of these 13 GWB's are polluted or are threatened by nitrate pollution from agricultural sources. In recent years, in our country, following European practices, more complex approaches to the assessment and monitoring of groundwater have been implemented. The Basin Directorates for Water Management (BDWM) were established with the main functions of coordination, monitoring, control and management of all water resources in the country. In fulfillment of their legal functions, the Basin Directorates issue permits for various types of water use from

ground water and surface water, at the request of the applicants. The directorates maintain their own monitoring of water quality in GWBs according to a number of indicators.

The basins of the individual GWBs are formed under the influence of physicogeographic (climate, relief, hydrology, hydrography) and geological factors (geological structure, lithological composition of rocks and tectonic structures), and are described in the specialized geological literature and hydrogeological maps of the Republic of Bulgaria. According to the methodology adopted in the EU and in our country for determining the GWBs, they are classified into several groups. For the Pleven region, the main 13 GWBs can be classified into the following 5 types:

3.1.GWBs in the Danube lowlands (2 items):

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

3.2. GWBs in the alluvial deposits of the rivers Iskar, Vit and Osam - right tributaries of the Danube (3 pieces):

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

3.3. GWBs in the interriver massifs in Northern Bulgaria on the territory of the Pleven Administrative Region (4 units):

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

3.4. GWBs in typical aquifers (2 pieces):

- GWB No. BG1G000N1BP036 – Karst waters in the Lom-Pleven Depression
- GWB No. BG1G0000K2M047 – Karst waters in the Lom-Pleven basin

3.5. GWBs located in karst basins on territories in fissure collectors (2 pieces):

- GWB No. BG1G0000K2S037 – Karst waters in the Fore-Balkans, along the rivers Ogosta, Vit, Iskar, Osam

- GWB No. BG1G00000K1040 – Karst waters in the Lovech-Tarnovo massif, between the rivers Vit, Osam and Yantra

A comprehensive review of the database within the Danube Region Basin Directorate revealed that nine Groundwater Bodies are susceptible to surface pollution from agricultural sources, given their position as a first aquifer. Notably, even karst GWBs, which may appear as the 2nd or 3rd aquifer in various locations, exhibit vulnerability in specific areas where they are exposed on the Earth's surface as the first aquifer (refer to figures 2 and 3)

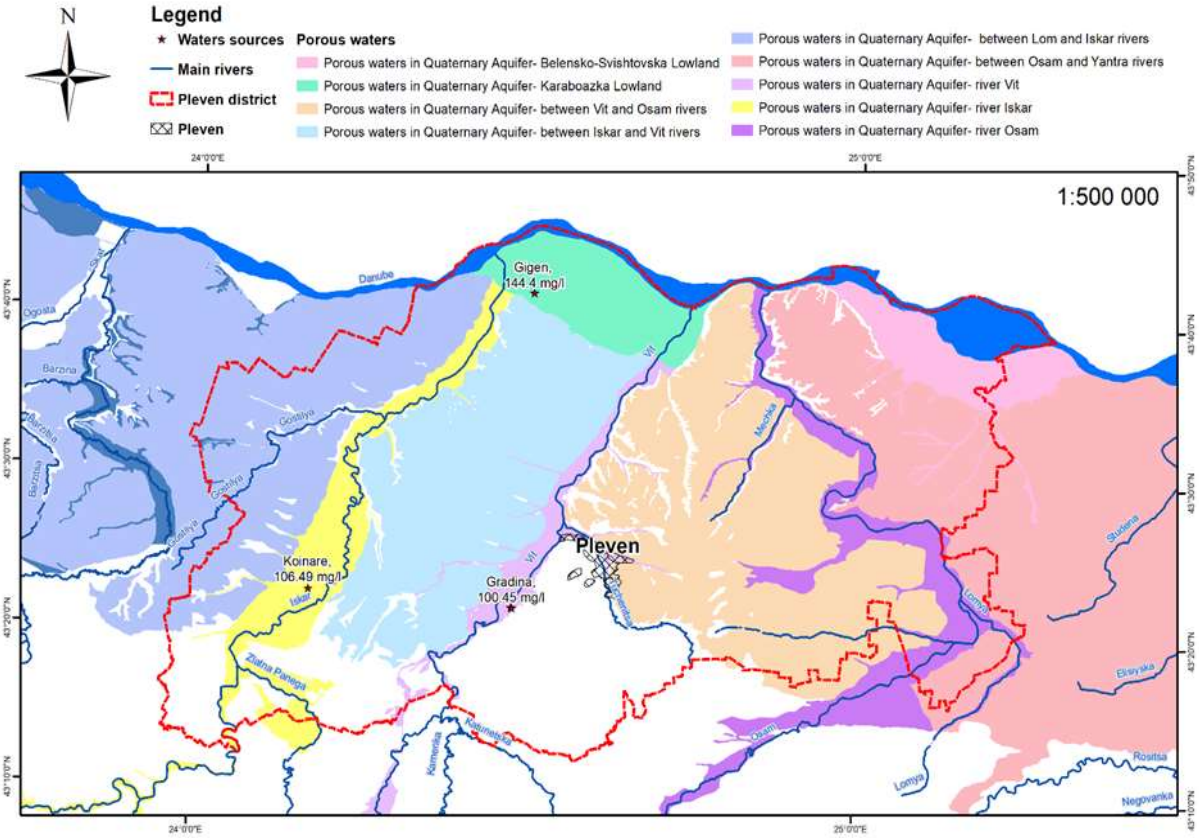

Figure 2- Porous GWBs in Pleven administrative region

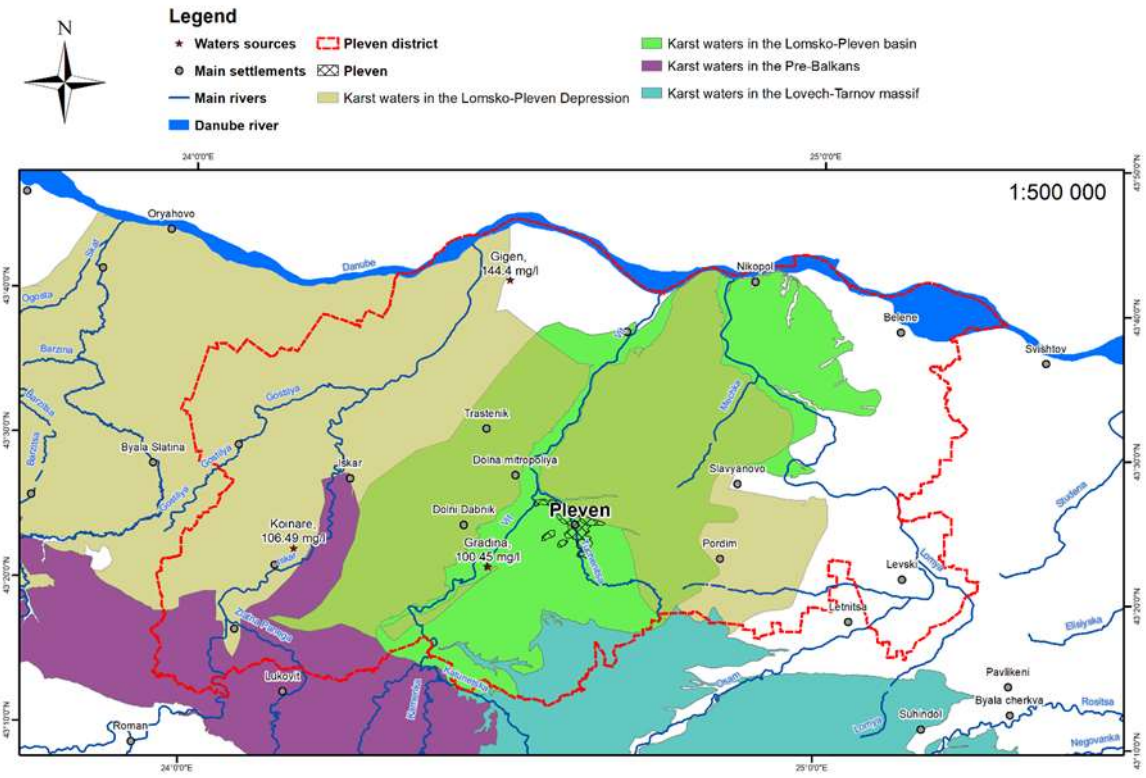

Figure 3 - Karst GWBs in Pleven administrative region

The listed groundwater bodies have specific characteristics as follows:

3.1.GWBs in the Danube lowlands (2 items):

- GWB No. BG1G0000QAL007 – Porous waters in the Quaternary – Karaboaz lowland (Fig. 2) - covers the territory with an area of 222.1 sq. km. and includes the descent along the right bank of the Danube River, bounded to the west and east respectively by the mouths of the Iskar River and the Vit River. The exposed area coincides with the total area of the GWBs. To the south, it extends several kilometers from the course of the Danube River.

An aquifer is formed in the gravelly-sandy layer, the level of which varies up to 5 m from the surface. The level of the aquifer varies depending on the height of the water in the river, due to the presence of a direct hydraulic connection. 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 fed by surface water infiltration from the Danube River and to a lesser extent from the geological substrate. The average thickness of the GWB is 20 m. The exploitation index of this GWB is 11%. Quantitatively, GWB No. BG1G0000QAL007 is not at risk. There is a risk to its chemical state due to the presence of point (pesticide storage and discharge of Domestic

waste water) and diffuse (agriculture and settlements without sewage) pollution sources. The degree of interaction of the GWB with surface waters is high, as there is a direct water exchange with the Danube River. Water abstraction for the purpose of public water supply from the GWB is carried out at several points - the "Brest" pump station, the "Creta" pump station, the "Gigen" pump station, the Somovit pump station and the "Zagrazhden" pump station.Only the PS "Brest" and PS “Gigen” have a registered permit for water use in the DRBD.

According to data from DRBD's own monitoring, the content of nitrates in this GWB is not the same in its different parts. For our research period DRBD has sampled from 3 points, where we observe the following values of nitrates according to the median: "TW9 -PS "Gigen" - 256.55 mg/L; ShW PS "Zagrazhden" - 16.48 mg/L; TW4 - PS "Brest" - 20.55 mg/L. The monitoring of the drinking water of RHI according to the nitrate indicator also shows permanently increased values in the water supply network of the villages of Gigen and Iskar (average value for the period in the village of Gigen - over 150 mg/ L, with a minimum of 105 mg/L and a maximum for the period of 215 mg/L, and for the village of Iskar respectively – 165 mg/L, 53 mg/L and 231 mg/L).

- Ground water body No. BG1G0000QAL008 - Porous waters in the Quaternary - Belensko-Svishtovska lowland (fig. 2) - is located on an area of 188.1 sq. km. and occupies the areas of the natural depression along the Danube river, bordered to the east by the town of Svishtov, and to the west by the town of Nikopol. In the southern direction, the GWB extends to the line of the village of Byala Voda and the village of Dekov (Belene municipality), reaching a width of up to 6 km. Its average thickness is 18 m. The western part of GWB No. BG1G0000QAL008 is included in the Pleven administrative region (Belene municipality), and the eastern part (Svishtov municipality) in the Veliko Tarnovo region. The level of underground water depends directly on the water levels in the river, due to the existing direct hydraulic connection with the Danube river, i.e. the degree of interaction with surface water is high. The covering layers in the GWB feeding area are characterized as sandy and swampy clays.

There is a tendency for increased iron and manganese content. On the territory of the GWB there are lands of the settlements of the Belene municipality and parts of the lands of the village of Lozitsa (Nikopol municipality) and the villages of Bojurluk and Stezherovo (Levski municipality). The natural water resources of GWB No. BG1G0000QAL008 are 634 L/s, and the permitted water quantities – 830 L/s (exploitation index 131%). The risk assessment regarding the quantitative and chemical status of Ground water body No.

BG1G0000QAL008 shows that it is at risk, and this pressure is contributed by both point (landfills and sewage discharge) and diffuse (agriculture and settlements without sewage) sources of pollution.

Water extraction for drinking purposes is carried out from several points, and there is a registered permit for water use for the water supply of the town of Belene and the town of Nikopol. The data from the DRBD's own monitoring shows the median nitrate content for the period of study, as follows: ShW PS Lozitsa - W&S Pleven – 22, mg/L; ShW-R1-PS "Belene" – 2.82 mg/L; ShW PS "Dragash Voivoda" - 19.44 mg/L.

On the territory of the Pleven administrative region, the right tributaries of the Danube - the rivers Iskar, Vit and Osam - are of great importance for water supply. On the river terraces in the flat part of the three rivers, alluvial deposits are formed in the flooded and non-flooded terrace in two layers - a lower gravelly-sandy layer and an upper sandy-clay layer. The alluvial deposits are placed on a bed of geologically diverse rock formations and ages. In the different sections of the rivers, the structure and composition of the geological substrate have a varying degree of influence, both on the quality of the accumulated water in the alluvium and on the accumulated water quantities. The underground water accumulated in the alluvial deposits of the rivers creates hydraulic connections and interactions with the river bed, which significantly increases the possibilities for water extraction.

3.2. GWBs in the alluvial deposits of the rivers Iskar, Vit and Osam - right tributaries of the Danube (3 pieces):

- Ground water body No. BG1G0000QAL017 – Porous waters in the Quaternary – Iskar River (fig. 2) - covers territories around the course of the Iskar River after the village of Gornik and the village of Chomakovtsi to the confluence with the Danube River. The total area of the GWB is about 350.8 sq. km. 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 and reaches 5-6 km, after which it narrows to the mouth. This determines the presence of more abundant water reserves in these sections compared to the lower course of the river to the mouth. The total area of alluvial deposits in the river terrace is estimated at 187 sq. km. Replenishment is provided by infiltration of precipitation falling on the surface of the terrace, as well as by ground water from aquifers on the substrate and by river water at high water of the Iskar River through the available hydraulic connections between the lower gravel-sand layer of the alluvium and the river waters. The average thickness of this GWB is 9.5 m, and the exploitation index is 11%.

Quantitatively, GWB No. BG1G0000QAL017 is not at risk, but its chemical status is threatened due to the presence of many diffuse and point sources of pollution.

Permits for water use from GWB No. BG1G0000QAl017 for drinking purposes were issued by DRBD for the lands of the village of Gornik, the village of Lepitsa, the village of Chomakovtsi, the village of Glava and the town of Koinare (all in the municipality of Cherven Bryag), the town of Iskar, Staroseltsi village, Dolni Lukovit village (Iskar municipality) and Brenitsa village (Knezha municipality) and some settlements from Dolna Mitropolia municipality - Bregare village, Gostilya village and v. Stavertsi. Monitoring of the Danube Region Basin Directorate for the 8-year period of our study was carried out at 3 points. The median values of nitrates for this period are as follows: ShW 1 - PS Suhace - 18.86 mg/L; ShW 1/70 PS "Gornik" Iskar - 36.81 mg/L and in ShW1 PS "Iskar" - 8.52 mg/L. According to the monitoring data of the DRBD for the water in this GWB, excessive nitrate values are not observed, but the monitoring of RHI-Pleven for the same period shows that the town of Koinare is one of the settlements in the Pleven region that show a permanently increased content of nitrates in drinking water (average about 106 mg/L).

- Ground water body No. BG1G0000QAL018 - Porous waters in the Quaternary - River Vit (fig. 2).

Vit river flows in two administrative districts – Lovech district in the south and in Pleven district to the mouth of the Danube river in the north. The total area of the GWB is 188.8 sq. km., which is completely exposed. In the recharge area, the overlying layers are sandy-clay deposits. The alluvial deposits along the Vit river were mainly formed in 2 sections. The first section is located in the upper course of the river in the lands of the village of Peshterna and the village of Uglen (Lovech region), whose reserves are poorly explored. In the lower reaches of the river, after the village of Sadovets, the next section of alluvial accumulations with different strip widths reaching up to 4 km is formed between the village of Krushovitsa, municipality of Dolni Dabnik and south of the village of Yasen, municipality of Pleven. Groundwater is fed by infiltration of rainwater falling on the terrace, by flowing surface water through hydraulic connections, and by inflow of groundwater from the pad. The underground flow is drained by the river Vit and is directed to the bed of the river or parallel to the current. Quantitatively, the GWB is considered endangered (exploitation index - 65%). Chemically, it is also at risk due to the presence of settlements without sewerage, intensive agriculture, extraction of underground resources, discharge of sewage and other point and diffuse sources of pollution. The degree of impact with surface water is average, as there is direct contact with the waters of the Vit river.

Along the terrace of the river Vit from south to north, several stations of shaft wells were built, drawing ground water from the water body for water supply. These are the water supply groups and pumping stations in the lands of the village of Krushovitsa (municipality of Dolni Dabnik), the village of Tarnene (PS "Peternitsa" - municipality of Pleven), the village of Bivolare (WSG "Bivolare" - municipality of Dolni Mitropolia), the village of Opanets (WSG "Opanets" - Pleven municipality), village of Kreta (PS "Creta" - Gulyantsi municipality). An official permit for water use for the purpose of drinking and domestic water supply, registered in the DRBD, is available only for some shaft wells used for the water supply of a part of the city of Pleven, of the village of Gradina, as well as for the water supply of the villages of Riben and Podem and for many companies. located in the western industrial zone of the city of Pleven and the lands of the villages of Yasen, Disevitsa and Turnene. The content of nitrates calculated from the median of the values measured for the 8-year period under the monitoring of DRP are as follows: Point ShW 12 PS "D. Mitropolia" – 8.22mg/L; Point ShW1 PS "Creta" – 26.21 mg/L. The monitoring data of RHI-Pleven show that in the village of Gradina the average value of nitrates in drinking water for the same period is above the norm - about 95 mg/L.

- Ground water body No. BG1G0000QAL019 – Porous waters in the quaternary Osm river (fig. 2).

The GWB includes territories from 2 neighboring districts located along the course of the Osam River. In the upper section along the course of the river, parts of the lands of the towns of Lovech, Doirentsi, Letnitsa (Lovech region) are included, and in the lower course (Pleven region) part of the lands of the town of Levski, the village of Obnova and other smaller settlements to the mouth of the river at the confluence and into the Danube. The GWB has a total area of 366.3 sq. km., which coincides with the value of its exposed area. Alluvial deposits are formed on a bed of materials and rocks of different geological composition and varying water abundance. Formation of alluvial deposits and formation of underground water reserves begin already in the mountainous part in the upper reaches after the town of Lovech. The terrace of the river Osam is long, and its width reaches 6-7 km in the area of the town of Levski.. Accumulated water in the GWB is fed by infiltration of rainwater that falls on the surface of the terrace and groundwater from aquifers on the pad. The reserves of ground water are not large, due to the small thickness of the gravelly-sandy layer. The ground water flow moves towards the bed of the Osam River and parallel to it. The average thickness of the GWB is 8.5 m. The degree of interaction of surface and ground waters is average and is characterized by direct water exchange with the Osam River. The feeding area is covered by a

layer of clayey-sandy sediments. The exploitation index of this GWB is 15%, indicating that its quantitative status is not threatened. The risk assessment regarding its chemical state shows that it is at risk of pollution, with point (pesticide storage and discharge of waste water) and diffuse (agriculture and settlements without sewage) sources of pollution affecting its chemical state.

At GWB No. BG1G0000QAL019, located along the course of the Osam River, several water intakes have been built for water supply to settlements on the territory of the two neighboring regions of Lovech and Pleven. In the Pleven region, with valid permits for water use for drinking and domestic purposes, registered in the BDDR are the water supplies of the town of Levski and the villages of Mechka, Asenovtsi, Asparuhovo and Muselievo. The content of nitrates (median) in the three monitoring points of BDDR for research by us during the period is as follows: Lovech, ShW1 PS "Balkan" – 19.38 mg/L; Asenovtsi, ShW2 PS "Asenovtsi" – 11.27 mg/L; Yoglav, ShW1 - "Umarevtsi" station - 47.27 mg/L. In the drinking-domestic water supply (DWS) of Cherkovitsa and Izgrev villages, which draw water from this GWB, but do not have an officially registered permit in BDDR, we have calculated an average value for nitrates in drinking water of about 61 mg/L.

3.3. Ground water bodies in the interriver massifs in Northern Bulgaria.

Four GWBs are included in this group in Pleven region: GWB No. BG1G0000QPL023, GWB No. BG1G0000QPL024, GWB No. BG1G0000QPL025, GWB No. BG1G0000QPL026. All of them are located in the western part of the Mizian hydrogeological region south of the Danube River (Lomsko-Plevenska depression). It is characteristic of these ground water bodies that the accumulated ground water fits into older geological structures, formed in more distant geological epochs - Pleistocene, Pliocene, Miocene. The formed ground aquifers are at different depths from the earth's surface. In areas with deep aquifers, groundwater protection is satisfactory and is further improved in areas with a well-developed loess cover layer, which has good filtration qualities and is characteristic of large parts of the Danube plain.

- Ground water body No. BG1G0000QPL023 – Porous waters in the Quaternary between the rivers Lom and Iskar (fig. 2) - it is located in the territories of the administrative districts of Montana, Vratsa and in the western part of the Pleven region along the river Iskar (city of Knezha, village of Brenitsa, village of Enitsa - municipality of Knezha; village of Dolni Lukovit - village of Stavertsi, villages Stavertsi, Krushovene, Baikal, Bregare - municipality of Dolna Mitropolia). Its total area is large – 2886.6 sq. km. The older geological structures are overlain by loess and later Quaternary deposits and are exposed in various parts

of the earth's surface, where groundwater flows as descending springs with a small flow rate between 0.5 and 5 L/s. The average thickness of this GWB is 25 m. The connection of ground and surface waters is difficult. Groundwater recharge is carried out mainly by infiltrated precipitation. The exploitation index is only 3%, which indicates a low risk in quantitative terms. Its chemical condition is at risk, and the sources of pollution are identical to those of the previous GWBs. For domestic water supply in the Pleven region, a registered permition for water use from GWB No. BG1G0000QPL023 is available only for one water source located on the land of the town of Knezha (ShW Peev kladenets, Asparuhov val area) and for the water supplies of the villages Enitsa and Lazarovo. The median value for nitrates in the GWB according to DRBD monitoring data was calculated for each point as follows: Enitsa, Drainage Enitsa - Asparuhov Val – 43.4 mg/L; Turnak, ShW-Kozya barda - W&S Vratsa - Turnak - 28.82 mg/L; Knezha, ShW - Petrol-DI-93-Dimitar Gharkov – 48.03 mg/L; Gabrovnitsa, ShW PS "Gabrovnitsa" – 18.6 mg/L.

- Ground water body No. BG1G0000QPL024 – Porous waters in the Quaternary

between the rivers Iskar and Vit (fig. 2) - has a total area of 766.8 sq. km and is located in the massifs between the Iskar and Vit rivers. A characteristic feature is the more strongly developed loess layer in the northern part of the water body towards the Danube river (from 5 to 25 m in the northern direction towards the river). To the west, the border of the GWB is limited by the course of the Iskar river (part of the land of the village of Telish (municipality of Red Beach), the town of Iskar, the village of Staroseltsi (municipality of Iskar), the village of Slavovitsa (municipality of Dolna Mitropolia)). To the north, the GWB borders the Karaboaz lowland (GWB No. BG1G0000QAL007). To the east, the border is the river Vit river and GWB No. BG1G0000QAL018. In the south, the border of the GWB reaches the lands of Gorna and Dolna Mitropolia, Gorni and Dolni Dabnik, the village of Krushovitsa, the village of Sadovets (municipality of Dolni Dabnik), the village of Telish (municipality of Cherven Bryag). Its average thickness is 20 m, and the connection with surface water is difficult. Precipitation infiltration is the main source of groundwater recharge, and its drainage is carried out through small springs with a small flow rate of 0.5 to 2 l/s, as well as groundwater outflow in the alluvial terraces of the rivers. GWB No. BG1G0000QPL024 has an exploitation index - 13%, i.e. there is no risk to its quantitative status. A risk exists regarding its chemical state, due to the presence of point (pesticide storage and discharge of DWW) and diffuse (agriculture and settlements without sewerage, underground resources) sources of pollution.

There are registered permits for drinking water use from GWB No. BG1G0000QPL024 for the following water sources: shaft wells in the lands of the town of Dolni Dabnik, the town of Iskar, shaft wells "Geranchetata" (municipality of Dolna Mitropolia) and drainages in the lands of the town of Trastenik and the village of Orehovitsa (municipality of Dolna Mitropolia) and the village of Pisarovo (municipality of Iskar).

The value (median) for nitrate content was determined from the DRBD monitoring data for each point: Pisarovo, drainage "Banyata" - "W&S" Ltd. – Pleven, D. Dabnik - 7.73 mg/L; ShW 2 "Brestaka" "W&S" Ltd. – Pleven - D. Dabnik - 27.85 mg/L; Reed, drainage "Štarbashki geranium" - PS - 5.39 mg/L.

This GWB could be an alternative water supply for the village of Iskar, as part of it is located on its land. The villages of Iskar and Gigen are supplied with water from GWB No. BG1G0000QAL007 and have permanently elevated levels of nitrates in drinking water.

- Ground water body No. BG1G0000QPL025 – Porous waters in the Quaternary between the rivers Vit and Osam (fig. 2).

The GWB is located on a total area of 998.9 sq. km and occupies the territory of the Pleven region between the rivers Vit and Osam. It is characterized by the development of a loess cover layer above the aquifer, which thickens in the direction from south to north towards the Danube River. This fact is generally favorable for improving the quality of groundwater, due to the good filtration properties of the loess cover. Limestone deposits in these geological structures in the Pleven region are very scarce, in contrast to the western part of the Lomsko-Plevenska depression (in the Vidin, Montana, Vratsa regions), where they are quite common. To the west, the border of the GWB is the Vit River (GWB No. BG1G0000QAL018), and to the north the Danube River and the Osam River (GWB No. BG1G0000QAL019). To the south, the border reaches the lands of the town of Pleven, Pordim, the village of Obnova (Levski municipality), and to the east the border is with GWB No. BG1G0000QAL019 (the lands of the town of Levski, the village of Malchika, the village of Bulgarene, Levski municipality). The average thickness of GWB No. BG1G0000QPl025 is calculated to be 30 m. The connection between ground and surface water is difficult. In quantitative terms, the GWB is not threatened (exploitation index – 17%). Its chemical condition is threatened, as pressure is exerted by various sources of pollution - agriculture, settlements without sewerage, sewage discharge, pesticide warehouses, etc.

In the central part of the Pleven region (the municipalities of Pleven, Levski, Pordim), quite a number of ground water abstractions have been realized from GWB No. BG1G0000QPl025

for the purpose of water supply to small settlements. Permits for water abstraction for public water supply have been registered for the following water abstractions: Drains in the lands of the villages of Malchika, Obnova, Balgarene, Letnitsa (Levski municipality), as well as shaft wells in the lands of Pordim, Levski and Slavyanovo (Pleven municipality). The village of Zgalevo is supplied with water from the same GWB, without a registered permit for this and shows an average value of nitrates according to the monitoring data of RHI-Pleven almost 50 mg/L (49.9 mg/L).

In this GWB, high values for nitrates (median) were established in all three monitoring points of DRBD for the period considered by us: Renewal, drainage - PS "Kalcheva Cheshma" - 72.84 mg/L; Kamenets, drainage "Kurtovets" PS "Kamenets" – 46.03mg/L; Levski, ShW-Cholakov invest - Levski - 114.75 mg/L.

- Ground water body No. BG1G0000QPL026 – Porous waters in the Quaternary

between the rivers Osam and Yantra (fig. 2) - its total area is 1976.5 sq. km on the territory of the administrative districts of Pleven and Veliko Tarnovo. Only a small part of this territory is in the Pleven region and includes the lands of the town of Nikopol, the village of Dragash voivoda, the village of Sanadinovo (municipality of Nikopol), the village of Dekov (municipality of Belene) and the village of Kozar Belene (municipality of Levski), located along the eastern border of Pleven district. The average thickness of the GWB is 25 m. Interaction with surface water is difficult. The covering layers in the GWB feeding area are loess deposits. The risk assessment regarding the quantitative status of Ground water body No. BG1G0000QPL026 shows that it is not at risk (exploitation index - 9%). The risk assessment of its chemical status indicates that this GWB is at risk, with chemical indicators being influenced by point (pesticide storage and waste water discharge) and diffuse (agriculture and unsewered settlements) pollution sources. In a relatively small area around the town of Nikopol, groundwater connected to this GWB is captured through drains (drainages in the lands of the village of Sanadinovo - municipality of Nikopol; village of Kozar Belene - municipality of Levski; town of Nikopol). For these catchments, there are registered official permits for water use for the purpose of drinking and domestic water supply. Most of the real water intakes are located on the territory of the neighboring district of V. Tarnovo, which is why the ground waters of this GWB have relatively less importance for the water supply of the settlements of the Pleven district. There are registered permits for water use for the city of Nikopol and the villages of Gradishte and Kozar Belene.

During the research period, DRBD carried out sampling for the purpose of monitoring from 4 representative points. The values for nitrates, calculated by us according to the median, are as follows: Varzulitsa, ShW PS "Varzulitsa" – 48.03 mg/L; Kozlovets, drainage "Gravitachen" PS "Kozlovets" – 42.72 mg/L; Pavlikeni, Drainage Gyur fountain Old drainage - "W&S" Ltd. – Yovkovtsi - 14.08 mg/L; Kozar Belene, Drainage-Glava Reka - "W&S" Ltd. – Pleven – 42.03 mg/L.

All the Ground water bodies listed up to this point are primary aquifers.

The water in the last two types of Ground water bodies (ground water bodies in typical aquifers and groundwater bodies located in karst basins in areas in fracture reservoirs) are karst. Karst waters are widespread throughout Northern Bulgaria.

Karst waters in the Mysia hydrogeological region were formed in the carbonate deposits in the older structures and periods: Pliocene, Miocene, Sarmatian, Senonian, Upper and Lower Cretaceous, Valangian, Upper Jurassic, Middle Triassic. In these geological structures, non-pressurized and less often pressurized groundwaters have formed. Over large areas, aquifers sink deep hundreds to thousands of meters below the surface, protecting them from surface influence and pollution. At the places of exposure of aquifers on the earth's surface, karst waters are captured for drinking water supply.

3.4. Ground water bodies in typical aquifers

- Ground water body No. BG1G000N1BP036 – Karst waters in the Lom-Pleven depression (fig. 3) - covers territories from the administrative districts of Vidin, Montana, Vratsa and Pleven. In the Pleven region, it extends to the territories of the region, located to the west of the river Iskar, and is relatively evenly represented in the territories of all its municipalities, with the exception of the municipality of Belene GWB No. BG1G000N1BP036 is distinguished by a very large total area - 6573 ,9 sq. km., the exposed part of which is 2,025 sq. km. The ground waters are attached to the carbonate deposits of older geological periods - Sarmatian and Middle Miocene, well represented in the Lomsko-Pleven depression of the Mysia hydrogeological region. In much of the four areas, the GWB is overlain by Pliocene and Quaternary overburden, and outcrops on the ground surface occur mainly along the periphery of the depression. The covering layers in the feeding zone are loess deposits, and mainly in the exposed parts. The average thickness is 250 m, and the interaction of surface and underground waters is extremely difficult. Quantitatively, this GWB is not threatened (exploitation index – 9%). Its chemical condition is threatened, and various

point and diffuse sources of pollution contribute to this - agriculture, settlements without sewerage, sewage discharge, pesticide warehouses, etc.

Groundwater recharge is mainly due to rainfall, and drainage through springs to the hydrographic network.

The calculated value of the median for the content of nitrates in the GWB in each of the 4 sampling points is as follows: Gramada, KWgroup – 5.18 mg/L; Doctor Yosifovo, KW PS "Dr. Yosifovo" – 9.56 mg/L; Knezha, TW 2 PS "Svinsko Ezero" – 15.63 mg/L and Cherven Bryag; ShW "TERA-Cherven bryag" – 9.38 mg/L.

In the Pleven region, Ground water was captured through tube wells from GWB No. BG1G000N1BP036, mainly for water supply to small settlements. Permits have been issued for water use for drinking purposes for the following settlements - the town of Knezha, the village of Orehovitsa (municipality of Dolna Mitropolia), the village of Totleben (municipality of Pordim), the town of Slavyanovo, the village of Mechka, the village of Disevitsa and the village of Brashlianitsa (municipality of Pleven).

- Ground water body No. BG1G0000K2M047 – Karst waters in the Lom -Pleven basin (fig. 3).

In the Pleven region, the water body extends to the territories of the region, located east of the Iskar river. The total area of the GWB is 2008 sq. km., with a relatively small part (364.2 sq. km.) being the exposed parts on the earth's surface, mainly in the eastern part of the area between the Vit and Osam rivers.

The northern borders of the GWB reach the line of the village of Brest, the town of Gulyantsi, the village of Cherkovitsa, the town of Nikopol. The western borders reach the river Iskar. The southern borders of the GWB reach the line of the village of Telish, commune. Cherven Bryag, town of Dolni Dabnik, town of Pleven.

According to DRBD data, this GWB is not represented only in the lands of the settlements of Knezha municipality, which is located to the west of the Iskar river.

Groundwater in GWB No. BG1G0000K2M047 is accumulated in old structures from the Upper Cretaceous geological period and the Senonian and Maastrichtian subdivisions, with the latter forming several aquifers at different depths. In some areas, the ground water has a pressure character (for example, in the town of Svishtov). The overlying layers in the recharge zone are Tertiary sediments.

The average thickness of this GWB is 130 m, and interaction with surface waters is difficult. Groundwater recharge is carried out mainly by precipitation infiltration, but due to significant afforestation there is also exchange between individual aquifers.

Groundwater drainage is carried out through springs in the valleys of small rivers - Tuchenishka, Mechenska bara, Pordimska reka and Barata river.

The risk assessment regarding the quantitative status of GWB No. BG1G0000K2M047 shows that it is not at risk (exploitation index - 5%). The risk assessment in terms of its chemical status shows that the water body is at risk, being affected by point (pesticide storage and discharge of DWW) and diffuse (agriculture and unsewered settlements) sources of pollution. There are registered permits for drinking water use from this GWB in DRBD for the following settlements: the cities of Pleven, Nikopol and Trastenik and the villages: Bohot, Radishevo, Tuchenitsa, Disevitsa, Petarnitsa, Kartozabene, Riben and Sadovets. The calculated median value of nitrate content in GWB No. BG1G0000K2M047 in each of the 6 monitoring points of DRBD is as follows: Pleven, KW PS "Kaylaka" – 32 mg/L; Pleven, C 46 "Yana" – 4.72 mg/L; Bezhanovo, KW - Kunivsko – "W&S"-Ltd.- Lovech - Bezhanovo - 29.53 mg/L; Riben, KW "Ezeroto" – 31.93 mg/L; Nikopol, KW Tekiski - "W&S"-Ltd.- Pleven - Nikopol - 10.7 mg/L; Sadovets, KW-Studen kladenets - "W&S"-Ltd. Pleven - Sadovets - 35.06 mg/L.

GWB No. BG1G000N1BP036 and GWB No. BG1G0000K2M047 have a huge area that covers a large part of the territory of the Pleven region. This means that they include some of the problem settlements and could be used as an alternative water source, but no data has been found on the depth at which they come out in the respective settlement.

3.5. Ground water bodies located in karst basins on territories in fissure collectors

- GWB No. BG1G0000K2S037 – Karst waters in the Fore-Balkans, along the rivers Ogosta, Vit, Iskar, Osam (fig. 3) - extends into the Pre-Balkan and covers part of the river basins of the Ogosta, Vit, Iskar, Osam rivers. Its territory covers an area of 1,486 sq. km., with an open area of 1,296.4 sq. km. The covering layers in the GWB feeding area are surface and underground karst forms. The extremely low exploitation index – 0.1% also shows the low pressure on its quantitative condition. Despite the presence of some point and diffuse sources of pollution – its chemical state is not threatened. According to data from DRBD's monitoring, the content of nitrates in this GWB is not the same in its different parts. For our research period DRBD has sampled from 5 points, where we observe the following values of

nitrates according to the median: Kunino, KW "The Devil's Mill" – “W&S” Ltd. Vratsa - Kunin - 33.8 mg/L, Tsakonitsa - KW "Krushata" - “W&S” Ltd. Vratsa – 3.79 mg/L, Kobilyak, KW "Kobilyak" – 9.04 mg/L, Dermantsi, KW "Batovo Lake" – 15.76 mg/L, Kameno pole, KW – 41.5 mg/L.

No permits were found for drinking-domestic water supply to settlements in the Pleven region from GWB No. BG1G0000K2S037.

- GWB No. BG1G00000K1040 – Karst waters in the Lovech-Tarnovo massif, between the rivers Vit, Osam and Yantra (fig. 3) - it covers part of the Vit, Osam and Yantra river basins, and a very small part of this GWB is located in the Pleven region. Its total area is 1,385 sq. km., with an open area of 1,377.8 sq. km. The covering layers in the GWB feeding area are surface and underground karst forms. There is no risk for its quantitative condition (exploitation index – 1%). Its chemical state is not threatened, despite the presence of some point and diffuse pollution sources. A registered permit for drinking water suply from this GWB was opened only for the village of Beglezh. The monitoring of DRBD, regarding the content of nitrates for research period by us in the 4 representative points where the sampling was carried out, shows the following median values: Samovodene, KW "Krajnata Cheshma" – 275.69 mg/L; Gorsko Slivovo, KW "Kalvinets" – 42.51 mg/L; Gostinia, Drainage "Gostinka" - “W&S” Ltd.- Lovech - 35.33 mg/L; Belyakovets, KW "Glavata" – 46.87 mg/L.

Ground water bodies No. BG1G000N1BP036, No. BG1G0000K2M047 and No. BG1G0000K2S037 in vertical relation have 1, 2, 3 aquifers, and the last one (GWB No. BG1G00000K1040) – only 1 and 2 aquifers.

The presence of significant differences in the content of nitrates in different points of the same water body is due to the presence of conditions for diffuse pollution of aquifers associated with the use of nitrogen fertilizers in agriculture.

4. Study of the corelation between the nitrate content in drinking water and the amount of precipitation in the area on a monthly, seasonal and annual basis.

In compliance with the requirements of the Law on Access to Public Information, NIMH - Pleven provided results on the amount of precipitation in the settlements in the Pleven region, which showed persistently high levels of nitrates in drinking water for the research period.

After the statistical processing of the data on the amount of precipitation and the content of nitrates in the drinking water of the settlements in the Pleven region, which showed

permanently high above-normal values of nitrates for the period, statistically significant dependencies were found in the following settlements:

- The villages of Gigen and Iskar;
- the village of Dragash voivoda;
- Cherkovitsa village.

The average seasonal value of nitrates is influenced by the amount (sum) of precipitation from the previous season, as the Pearson's Correlation Coefficient (r=-0.538) shows an inverse proportional relationship - with an increase in the amount of precipitation in the previous season, the nitrate content in drinking water decreases waters of the villages of Iskar and Gigen.

The same inverse proportional relationship - shifted by one season - was found between the sum of precipitation by season and the seasonal median of nitrates (Pearson's correlation coefficient r = -0.528) - as the sum of precipitation in the previous season increases, nitrates in drinking water decrease.

A statistically significant inverse relationship between the monthly amount of precipitation and the average monthly concentrations of nitrates for the village of Dragash voivoda, Nikopol municipality (Spearman's coefficient = - 0.292, p = 0.015 < 0.05) – as the amount of monthly precipitation increases, the average monthly concentration of NO3 in drinking water decreases.

Near the village of Cherkovitsa, Nikopol municipality, there is an inversely proportional relationship between the annual amounts of precipitation and the nitrate annual median (Spearman's coefficient = - 0.714), which means that with an increase in annual precipitation, the annual nitrate median decreases.

For the rest of the settlements showing permanently elevated nitrate values, no reliable correlations were found between the amount of precipitation and the average values and medians for NO3 on a seasonal, monthly and annual basis.

5. Spatial analysis of specific water sources in a GIS environment. Specific factors influencing nitrate pollution - topography, land use, direction of accumulation flows in the relevant watershed, etc.

In this stage of our study, Geographical Information Systems were used, as they integrate spatial and descriptive information about various objects and events. Through GIS, information related to geographic location is created, stored, processed and analyzed,

revealing new spatial relationships and patterns. The applications of GIS are multi-faceted and varied and include - modeling situations and events (considering different scenarios), tracking different processes in time and space (spatial analyses), mapping, field work, data management, remote sensing processing and analysis.

For each of the water sources with the highest excess values of nitrates in drinking water - the village of Gigen and the town of Koinare (over 100 mg/L), a watershed was modeled in order to establish the expected direction of accumulation flow of different types of surface water - precipitation, waste, irrigation, etc. The Watershed tool was used to model the watershed, which projects the accumulation and the direction of water outflow (accumulation flow). Watershed modeling is based on a Digital Elevation Model (DEM) raster layer - at a resolution of 20 m. For further analysis, a slope raster layer obtained as a derivative with the Slope tool of ArcMap was used. After modeling the watershed, an area (buffer) with a certain radius is determined for each water source (in our study, the radius is 100 m). This buffer is used to determine the slope of the terain using the Extract by mask tool. From the resulting layer, statistics for the minimum, maximum, mean and standard deviation (SD) of the slope in the buffer zone, as well as the range (the difference between the minimum and maximum value in degrees) were extracted using the Zonal Statistics tool.

For each watershed, the type of land use is also visualized, through Corine Land Cover 2018. The percentage ratio of the different types of land use for the respective catchment is also determined - arable areas without irrigation systems, pastures, vineyards, deciduous forest, orchards and forest fruit plantations, water areas and others.

5.1. Spatial analysis of the water sources of the village of Gigen and the village of Iskar.

The above-mentioned two villages have a common water supply, which is carried out by 4 tube wells located in the immediate vicinity of the village of Gigen, and the village of Iskar is located about 4 km from the village of Gigen.

The "Ghigen" pumping station has registered permition for water use from ground water and has a sanitary-security zone.

The four tube wells of the village of Gigen are located at the southeastern end of the village and are located in a slightly shaped funnel, as in the 100-meter buffer zone around the water source, the slope is quite slight ($\bar{\chi}$ = 3.22^{o}, range 0 – 8.32^{o}, Table 4) directed inwards towards the water source. This is a prerequisite for the collection to the wells of runoff water contaminated with nitrates (median for the period - 144.4 mg/L) from various sources, in this case mainly agricultural lands. The reservoir flow leaves the catchment area in a southeasterly

direction through the lowest point in the topography of the catchment (the drawdown point), which is 1267 m from the wells.

Table 4 - 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	SD
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 (34,260 decares). Land use in the watershed includes the following types of land: Non-irrigated arable land - 84.6%; Broad-leaved forest – 6.22%; non-developing urbanized structures (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 5).

Annual nitrogen fertilization is applied only to the lands in the catchment area defined as land use category " Non-irrigated arable land ", which represents a relative share of 84.6% (2896.7 ha) of the entire catchment area (Table 5, Fig. 4).

The water protection zone of the water source of the village of Gigen has an area of zone III around the 4 tube wells of 1302 decares and zone II – 432 decares. A ban has been placed on the application of nitrogen fertilization on the area of zone II of the WPZs and a limited application is recommended on the territory of zone III, without determining the extent of the restriction. The territory of zones II and III is 100% occupied by agricultural lands, classified as cultivated areas without irrigation systems.

Table 5 - 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		

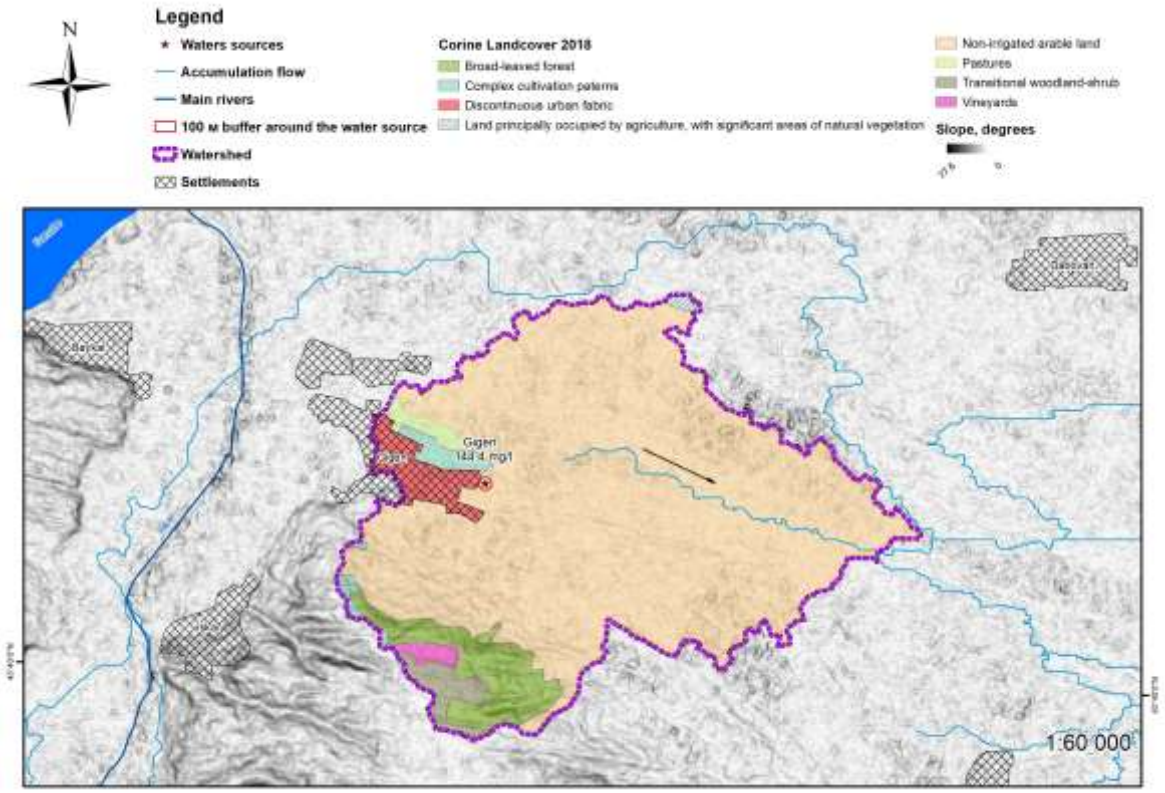

Figure 4 - Type of land use, accumulation flow and direction of outflow at the water source of the village of Gigen

5.2. Spatial analysis of the water source of Koinare.

The city of Koinare is supplied with water from GWB No. BG1G0000QAL017 – Porous waters in the Quaternary - Iskar river. This GWB covers territories around the course of the Iskar River after the village of Gornik and the village of Chomakovtsi to the confluence with the Danube River. The total area of the GWB is about 350.8 sq. km. 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 and reaches 5-6 km, after which it narrows to the mouth. This determines the presence of more abundant water reserves in these sections, compared to the lower course of the river.

The modeled watershed around the water source for the town of Koinare covers an area of 5174 ha (51740 decares) (Table 5).

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%; pastures – 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 5, Fig. 5).

The spatial analysis of the territory around the water sources of the town of Koinare showed a similarity with the situation in the village of Gigen – a relatively weak slope in the buffer around the water source ($\bar{\chi}$ = 3.37o, range 0 – 7.16^{o}, Table 4) and a distance of 116 m from the outlet of the accumulation flow (drain point). For our research period (2010-2017), the median nitrate content in the water source of Koinare is 106.5 g/L.

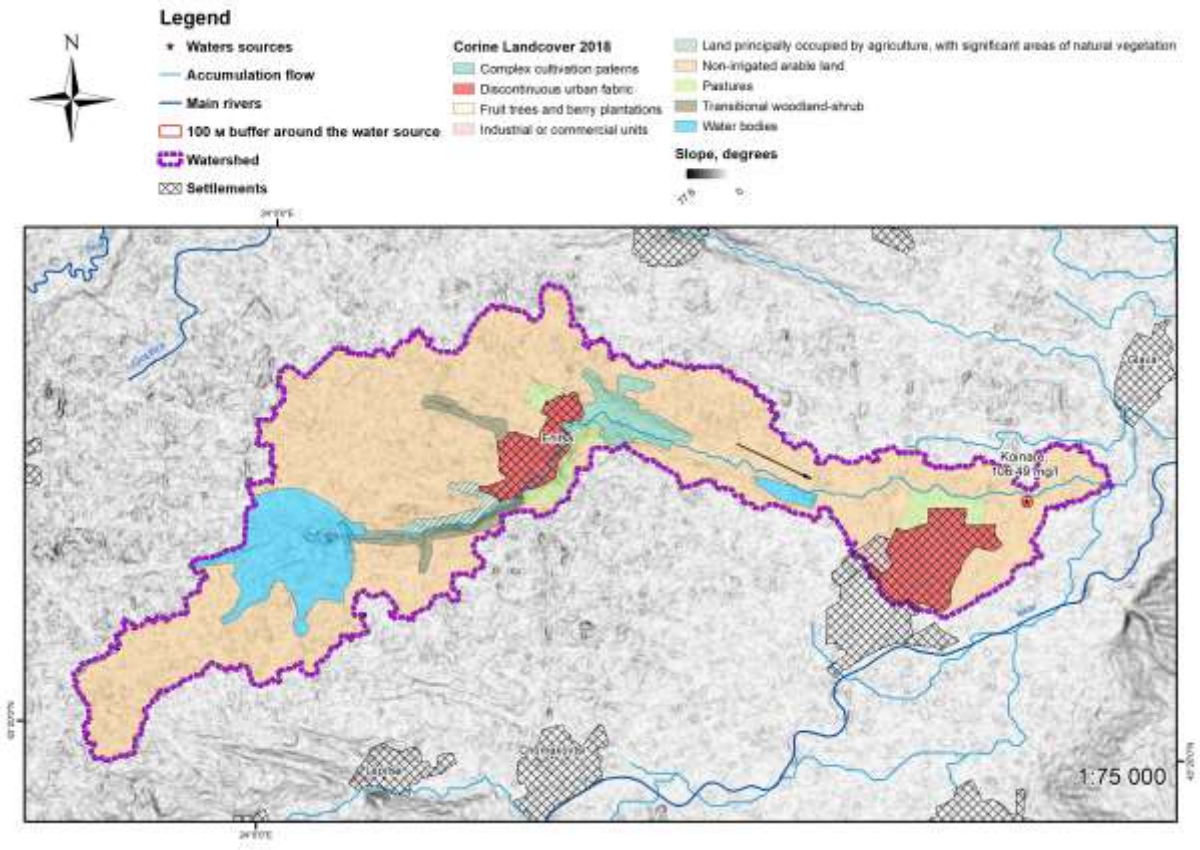

Figure 5 - Type of land use, accumulation flow and direction of outflow at the water source of the town of Koinare

VI. DISCUSSION OF THE RESULTS

In the past, most of the settlements in Bulgaria were built mainly around natural water sources. The construction of central water pipes in the country began en masse in the second half of the 20th century. This implies a high degree of depreciation of water pipes and water supply facilities, as well as difficulties in complying with the newly introduced European and national regulatory requirements in the management of the water sector. Another particularly important obstacle in the management of the water sector in Bulgaria and making the right management decisions is that the available data and information are scattered in many institutions and commercial companies. The main functions of management and regulation of the accessibility and quality of water supply and sewage services in the Republic of Bulgaria are assigned to the so-called "W&S operators".

The water supply in the Pleven region is served by “W&S” Ltd. - the city of Pleven, and the water supply network in the region covers 100% of the settlements and has a total length of 3044 km. The company is divided into 10 production areas, which are responsible for the water supply and sewage management of the area - Pleven District - City, Pleven District - Municipality, Gulyantsi District, Dolna Mitropolia District, Levski District, Belene District, Nikopol District, Cherven Bryag District, Knezha District and WWTP – Bozuritsa village.

The settlements in the district have access to drinking water for public use, which in the majority of cases meets the standards laid down in the Bulgarian legislation (Regulation No. 9). Exceptions are made by the 8 settlements, showing a permanent excessive content of nitrates for the research period (the villages of Gigen, Iskar, Gradina, Dragash voivoda, Izgrev, Cherkovitsa, Zgalevo and the town of Koinare).

The average value for nitrate content for the 8-year period ranged from 50.61 mg/L to 150.68 mg/L, which exceeded the norm of 50 mg/L up to 3 times.In nine of the settlements, the average value is within 35 mg/L - 50 mg/L, and only in some months and years the nitrate content exceeds the maximum value (50 mg/L) (Table 3).

The water sources with non-standard values of nitrates are relatively evenly distributed throughout the territory of the district. Only in three of the small municipalities (Belene, Iskar and Knezha) were no nitrate-contaminated water sources found. In all other 8 municipalities, there are between 1 and 3 nitrate-contaminated water sources. The water supply systems affected by pollution are intended for water supply to small settlements - mostly villages.

Excessive nitrate values were found in 16 villages and only in 1 city (Koinare town, Cherven Bryag municipality).

For water supply in the Pleven region, groundwater is used almost exclusively, which is extracted from 13 ground water bodies located in the Danube region of basin management. A total of 50 underground water bodies are located on the territory of DRBD, which are located vertically in 6 GIS layers

• Layer 1 – Neogene-Quaternary – 33 pcs.
• Layer 2 – Neogene – 3 pcs.
• Layer 3 – Neogene – Sarmatian – 2 pcs.
• Layer 4 – Upper Cretaceous – 4 pcs.
• Layer 5 – Triassic-Jurassic-Cretaceous – 7 pcs.
• Layer 6 – Lower Cretaceous-Malm-Valange – 1 pc.

Groundwater monitoring is carried out in 2 main directions by the Basin Directorates:
- Groundwater quality monitoring (chemical condition);
- Monitoring of the quantitative state of groundwater.

The tube wells of the village of Gigen, from which the village of Iskar is also supplied with water, draw water from GWB No. BG1G0000QAL007 - Porous waters in the Quaternary – Karaboaz lowland, locked between the Danube River and the mouths of the Iskar and Vit rivers. This GWB has an area of 222.1 sq. km and is positioned in Layer 1 - Neogene-Quaternary or first aquifer to the earth's surface. The GWB is in direct hydraulic connection with the Danube River.

One of the main reasons for the high nitrate load in the drinking water of the villages of Gigen and Iskar is the pressure from diffuse sources of pollution, mainly agricultural activities, since in the territory of Gulyantsi municipality, cultivated agricultural land is 85% of its total area.

The movement of the accumulated water in the GWB is in the direction of the Danube river. The chemical condition of GWB No. BG1G0000QAL007 is evaluated in 2 monitoring points - village of Brest - TW4 - PS "Brest", Gulyantsi municipality and village of Gigen "TW9 PS "Gigen", Gulyantsi municipality.

Ground water body No. BG1G0000QAL007 is also used for independent water supply to the villages of Brest, Zagrazhden, Kreta and Somovit. 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 amount of water in these water supply areas is between 50 and 390 cubic

meters/day and they are at a distance from Gigen station between 10-30 km. Therefore, the water sources of these settlements could be used to dilute the high nitrate waters of the village of Gigen after providing the relevant infrastructure. As an alternative water source or source of water for mixing with the waters of PS Gigen, we exclude PS Brest, since the water coming from it is compromised according to another indicator - total chromium. Historical studies and information from the DRBD indicate that the excess chromium content is due to its natural content in the loess deposits, influencing the chemical composition of the groundwater in the area.

In the lands of the villages of Gigen and Iskar, there are also GWB with codes: BG1G0000QAL017, BG1G0000QPL024 (Table 6), which could be used for water supply, but in DRBD there is no information about the depth of their aquifer in this land, as well as what is the content of nitrates in these two ground water bodies, since there are no sampling points located near the village of Gigen and the village of Iskar. From GWB BG1G0000QAL017 there are organized water supplies in the upper course of the Iskar River, which have standard values for nitrates, but they are at a great distance from the village of Gigen, which makes them practically impractical as an alternative water source for the village of Gigen. Given the above considerations, we propose as a measure to achieve the main goal, mixing water extracted from the functioning water source for the village of Gigen and the village of Iskar with previously calculated amounts of water extracted from one of the operating water sources from the same GWB for the villages of Zagrazhden, Kreta or Somovit. In the specific case, such mixing carries a minimal risk, due to the available hydraulic connections of the underground water body with the Danube River, whose waters contain a minimal amount of nitrates.

Town of Koinare with an average value of nitrates in drinking water for the period 2010-2017 – 106.24 mg/L (Table 3), uses water from GWB No. BG1G0000QAl017 for its water supply. The chemical status of this GWB is highly threatened due to the presence of many diffuse sources of pollution - agriculture, lack of sewage in some settlements, extraction of underground resources, and less point sources. The vulnerability to pollution from diffuse sources is also increased by the fact that GWB No. BG1G0000QAl017 is also in Layer 1 - Neogene-Quaternary or first aquifer to the earth's surface. The chemical condition is monitored in 3 monitoring points - the village of Gornik, the town of Iskar and the village of Lepitsa. The results of the monitoring for 2018 show standard water by all indicators in all 3 points and only in the village of Brest - individual cases with excessive nitrate values. Permits

for drinking and domestic water supply from GWB No. BG1G0000QAl017 were issued by DRBD for the lands of the village of Gornik, the village of Lepitsa, the village of Chomakovtsi, the village of Glava and the town of Koinare (all in the municipality of Cherven Bryag), the town of Iskar, the village of Staroseltsi, Dolni Lukovit village (Iskar municipality) and Brenitsa village (Knezha municipality), as well as some settlements from Dolna Mitropolia municipality - Bregare village, Gostilya village, Stavertsi village. In none of the above-mentioned settlements was an excessive content of nitrates in the drinking water recorded during the studied period. The water source of the town of Koinare does not have a water protection zone officially established by order of the director of the DRBD, which prevents the imposition of prohibitions and restrictions related to nitrogen fertilization of agricultural lands, which occupy 73% of the watershed of the water source of the town of Koinare.

In the land of the town of Koinare there is also GWB No. BG1G000N1BP036 - Karst waters in the Lom-Pleven depression (Table 6), which is in Layer 3 - Neogene-Sarmatian. This GWB is distinguished by a relatively large area (6573.9 sq. km), covering the territories of 4 regions - Vidin, Montana, Vratsa, Pleven. Its chemical condition was monitored in 4 monitoring points, 2 of which are not on the territory of the Pleven region (KW PS "Dr. Yosifovo", Montana municipality and Gramada group KWs village, Gramada municipality). The monitoring points located on the territory of the district (TW 2 PS "Svinsko Ezero", town of Knezha, municipality of Knezha and ShW "TERA-Cherven Bryag", town of Cherven Bryag, municipality of Cherven Bryag) show that the water in this part of the underground water body does not exceed the norms according to the observed indicators. Permits for water use for drinking purposes issued by GWB No. BG1G000N1BP036 are available for the following settlements - the town of Knezha, the village of Orehovica (municipality of Dolna Mitropolia), the village of Totleben (municipality of Pordim), the town of Slavyanovo, the village of Mechka, the village of Disevitsa and Brashlianitsa village (Pleven municipality).

No data were found about the depth of the aquifer on the territory of the city of Koinare, which prevents the selection of this GWB as an alternative water source for the city. At a relatively short distance from the town of Koinare, there is a water supply for the town of Knezha from the same GWB, with standard values for nitrates and other monitored indicators. The town of Koinare is the settlement with the largest population exposed to nitrates in the Pleven region (3706 inhabitants, Table 3), which is a prerequisite for considering the possibility of reducing nitrates in drinking water - in the absence of an alternative for selecting a new water source. A possible solution is the construction of a drinking water treatment plant

including a denitrification stage. An answer to the question of which of the two options is more profitable should be given after a thorough professional financial and economic analysis, which should be prepared and accepted by the relevant water supply company. There are three arguments in favor of the option with the introduction of denitrifying technology:

- Availability of effectively functioning similar facilities in Europe for small and medium-sized water supply systems;
- the available capacity of the current water source for extracting a sufficient amount of water of good quality (with the exception of the nitrate indicator);
- built infrastructure to the functioning water source (pipelines and other engineering facilities).

Table 6 – Ground water bodies available in the lands of settlements using drinking water with elevated nitrate values

№	settlements	municipality	GWB in the lands of the settlements	
			number	Code of GWB
1	3	4	5	6
1.	v. Gigen v. Iskar	Gulyantsi	3	BG1G0000QAL007/ BG1G0000QAL017/ BG1G0000QPL024
2.	town Koynare	Cherven bryag	2	BG1G0000QAL017/ BG1G000N1BP036
3.	v.Gradina	Dolni Dabnik	3	BG1G0000QAL018/ BG1G000N1BP036/ BG1G0000K2M047
4.	v.Dragash voivoda	Nikopol	2	BG1G0000QPL026/ BG1G0000K2M047
5.	v.Izgrev	Levski	2	BG1G0000QAL019/ BG1G0000QPL026
6.	v.Cherkovitsa	Nikopol	4	BG1G0000QAL019/ BG1G0000QPL025/ BG1G000N1BP036/ BG1G0000K2M047
7.	v.Zgalevo	Pordim	3	BG1G0000QPL025/ BG1G000N1BP036/ BG1G0000K2M047
8.	v.Pelishat	Pleven	3	BG1G0000QPL025/ BG1G000N1BP036/ BG1G0000K2M047
9.	v.Radishevo v.Tuchenitsa	Pleven	2 1	BG1G0000QPL025/ BG1G0000K2M047 BG1G0000K2M047
10.	v.Borislav	Pordim	1	BG1G0000QPL025
11.	v.Obnova	Levski	3	BG1G0000QPL025/ BG1G0000QAL019/ BG1G000N1BP036
12.	v.Bozhuritsa	Dolna Mitropolia	4	BG1G0000QAL018/ BG1G0000QPL025/ BG1G000N1BP036/ BG1G0000K2M047
13.	v.Petarnitsa	Dolni dabnik	1	BG1G0000K2M047
14.	v.Gortalovo	Pleven	1	BG1G0000K2M047
15.	v.Gornik	Cherven bryag	2	BG1G0000QAL017/ BG1G0000K2S037

The average value for nitrates in the drinking water of the village of Gradina for the research period exceeded the norm almost 2 times (95.34 mg/L, Table 3). The water supply facilities of the village (2 shaft wells) draw water from GWB No. BG1G0000QAL018 – Porous waters in the Quaternary – River Vit, which is in Layer 1 – Neogene-Quaternary and its total area of 188.8 sq. km is fully exposed. This means that it is vulnerable to pollution from surface diffuse sources - intensive agricultural activities, the presence of settlements without sewage, etc. Its chemical condition is monitored in 2 monitoring points - at the town of Dolna Mitropolia ShW12 of the PS "D. Mitropolia", Dolna Mitropolia municipality and at the

village of Kreta ShW1 of the "Kreta" police station, Gulyantsi municipality. The point at Dolna Mitropolia for the year 2018 shows a good chemical state of the water with single exceedances of the norm for nitrates and orthophosphates. Monitoring point near the village of Kreta shows a single exceedance of the norm for iron and several exceedances of the norm for ammonium ions and manganese. Part of the town of Pleven, the villages of Riben and Podem and many companies located in the western industrial zone of the town of Pleven and the lands of the villages of Yasen, Disevitsa and Turnene are also supplied with water from GWB No. BG1G0000QAL018.

In the land of the village of Gradina, there are also GWB No. BG1G000N1BP036 - Karst waters in the Lom-Pleven Depression and GWB No. BG1G0000K2M047 - Karst waters in the Lom-Pleven basin (Table 6), which could be used for the extraction of drinking water. For GWB No. BG1G000N1BP036 there is no data on the depth of the aquifer near the village of Gradina. GWB No. BG1G0000K2M047 is in Layer 4 - Upper Cretaceous and has a total area of 2008 sq. km., a very small part of which is exposed (364.2 sq. km.). Its chemical condition is monitored in 6 monitoring points - KW PS "Kaylaka" Pleven, Pleven municipality; Riben village, KW "Ezeroto", Dolna Mitropolia municipality; C46 "Yana" Pleven, Pleven municipality, Nikopol city, KW "Tekiyski", Nikopol municipality; Sadovets KW "Studen Kladenets", municipality of Dolni Dabnik, which show that there is no exceedance of the observed indicators. However, there is no data on the depth of the aquifer in the land of the village of Gradina, which would make it difficult to decide on its use as an alternative water source for the village.

In the village of Dragash voivoda, the average value of nitrates (76.65 mg/L, Table 3) in drinking water for the period also significantly exceeded the norm of 50 mg/l. The village draws water for drinking and domestic needs from GWB No. BG1G0000QPL026 – Porous waters in the Quaternary between Osam and Yantra rivers, which is in Layer 1 – Neogene-Quaternary. Its chemical state is influenced by point (pesticide storage and discharge of BOW) and diffuse (agriculture and settlements without sewage) pollution sources. Its condition is monitored in 4 monitoring points: the village of Varzulitsa, ShW PS "Varzulitsa", Polski Trambesh municipality, Veliko Tarnovo region; village of Kozlovets drainage "Gravitachen" PS "Kozlovets", Svishtov municipality, Veliko Tarnovo district; Pavlikeni, Dr. Gyur spring Old drainage - Yovkovtsi waterworks, Pavlikeni municipality, Veliko Tarnovo district; Kozar Belene village, Glava reka drainage, Levski municipality, Pleven district. Only the station in the village of Kozlovets shows an increase in nitrates for the last few years, and in the other stations there are one-time exceedances of some indicators - iron, manganese,

orthophosphates, permanganate oxidizability and chromium, which may be due to a malfunction in the aquifer facility or non-compliance with the standards for sampling at the discretion of the control authority (DRBD). On the territory of the village of Dragash voivoda, there is also GWB No. BG1G0000K2M047 - Karst waters in the Lom-Pleven basin (Table 6), which, as mentioned above, is in Layer 4 - Upper Cretaceous and its chemical condition according to the information from The 6 monitoring points are good and there is no excess of the monitored indicators. No data were found on the depth of the aquifer in the village land, which would make it difficult to decide on its use as an alternative water source for the village of Dragash voivoda.

The village of Izgrev, Levski municipality shows an average value of nitrates of 61.33 mg/L (Table 3). The village has its own water supply, carried out by three drains and one tube well, which draw water from GWB No. BG1G0000QAL019 – – Porous waters in the Quaternary Osam River. The GWB includes territories from 2 neighboring districts located along the course of the Osam River - Lovech and Pleven. It is located in Layer 1 – Neogene-Quaternary and its chemical condition is monitored in 3 monitoring points: town of Lovech ShW1 PS "Balkan", municipality of Lovech; Asenovtsi village ShW 2 Asenovtsi pumping station, Levski municipality and MR 290 near Yoglav village ShW1 Umarevtsi pumping station, Lovech municipality. The risk assessment regarding its chemical status indicates that it is at risk of contamination due to the presence of diffuse (agriculture and unsewered settlements) and point (pesticide storage and DWW discharge) sources of pollution. The monitoring point near the village of Joglav shows a permanent increase in the nitrate content above the norm for the last few years. By all other indicators, the water meets the quality standard. In the land of the village of Izgrev, there is also GWB No. BG1G0000QPL026 – Porous waters in the Quaternary between the rivers Osam and Yantra (Table 6), which is also compromised in terms of nitrates, which is why it is not a good option for an alternative water source.

From GWB No. BG1G0000QAL019 – Porous waters in the Quaternary Osam river is also supplied with water to the village of Cherkovitsa, which has similar average values of nitrates for the period - 61.27 mg/L (Table 3).

In the land of the village there are 3 more ground water bodies - GWB No. BG1G0000QPL025 - "Porous waters in the Quaternary - between the rivers Vit and Osam", GWB No. BG1G000N1BP036 - Karst waters in the Lom-Pleven Depression and GWB No. BG1G0000K2M047 - Karst waters in the Lom-Pleven basin (Table 6).

GWB No. BG1G0000QPL025 is in Layer 1 – Neogene-Quaternary and is located on a total area of 998.9 sq.km, occupying the territory of the Pleven region between the rivers Vit and

Osam. Its chemical condition is threatened, as pressure is exerted by various sources of pollution - agriculture, settlements without sewage, etc. Its condition is monitored in 3 monitoring points (Obnova village, Kalcheva chesma drainage station, Levski municipality; Kamenets village, Kurtovets drainage, Kamenets station, Pordim municipality; Levski town, Cholakov Invest - Levski , Levski municipality), in which high concentrations of nitrates are reported. This means that even if it is close and easily accessible, it is not a suitable option as an alternative water source for the village of Cherkovitsa. There is a lack of data on the depth of the aquifer of GWB No. BG1G000N1BP036 and GWB No. BG1G0000K2M047 in the land and this village, which would make it difficult to make a decision on the selection of these two GWBs as an alternative source of water supply.

The village of Zgalevo is supplied with water from GWB No. BG1G0000QPL025 and shows an average value of nitrates for the period – 50.61 mg/L (Table 3). In the land of the village, GWB No. BG1G000N1BP036 and GWB No. BG1G0000K2M047 are also available (Table 6), and here too there is no data on the depth of the aquifer, which is why it is not possible to give a clear answer regarding the alternative use of these water bodies for water supply the village.

Table 7 - Manufacturer's instructions for professional use of ammonium nitrate

№	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 *или* 3/3 in the spring

Table 7 presents the specific guidelines for the recommended doses of ammonium nitrate for fertilizing different agricultural crops. For example, for the most common cereal grown in our

country (wheat), in compliance with the given recommendations, amounts of ammonium nitrate between 230-410 kg/ha are applied. In the specific case of the village of Gigen and the village of Iskar, the watershed modeled in the GIS environment around the wells of the village of Gigen has an area of 3426 ha (34260 decares) (Table 5), and 85% of this area is occupied by cultivated areas without irrigation systems (Non-irrigated arable land), (29121 decares). At a minimum recommended dose for ammonium nitrate of 230 kg/ha, the amount of ammonium nitrate applied in the watershed area is around 669783 kg. Applying the maximum recommended dose of 410 kg/ha, the amount of ammonium nitrate introduced into the watershed around the water sources of the village of Gigen would be 1193961 kg. There is no consensus in the literature on the extent of nitrate uptake by vegetation, as well as precise quantitative data on migration of nitrates to groundwater, but it is believed that the applied amount of ammonium nitrate is absorbed around or slightly more than 2/3 of the applied dose. The undigested amount of ammonium nitrate remaining in the catchment area is within 223,261 - 397,987 kg. The undigested amount replenishes the soil nitrogen reserves, and part of it remains in dissolved form with sufficient humidity. The remaining part is subject to vertical migration to the groundwater of the first aquifer and horizontal migration along the earth's surface as part of the accumulated water flow around the water source and may also fall into it. In the specific case at the water source of the village of Gigen, the groundwater drainage is carried out in a north and north-easterly direction towards the Danube river and part of the nitrates migrating with the water inevitably feed the water source with water enriched with nitrates. This process of nitrates entering the water source is greatly facilitated in the presence of a pronounced slope of the earth's surface towards the place of water extraction and when the water source occupies the lowest point of the relief.

The lowest are the recommended doses for application of ammonium nitrate in canola. In this case, under the same area and conditions, the amount of ammonium nitrate required for the cultivation of this agricultural crop is in the range of 513,900 - 685,200 kg. With the same digestibility, this corresponds to a residue of ammonium nitrate not absorbed by the vegetation within 128,475 - 171,300 kg.

The spatial analysis of the water sources near the village of Gigen shows that the watershed modeled in the GIS environment (34,260 decares) significantly exceeds (80 times) in area the established WPZ of the same water source (zone III - 1302 decares and zone II - 432 decares). It is obvious that not the entire amount of undigested ammonium nitrate enters the water of the water source, but the modeled area is many times larger than the area of zone II, determined by the previous methodology.

Table 8 – Nitrate nitrogen content [mg/l] in the Iskar, Vit, Osam and Danube rivers for the period 2010-2017

Point	r.Iskar-v.Gigen		r.Iskar-v.Reselets		r.Vit after Gulyantsi		r.Vit after Sadovets		r.Osam-v. Cherkovitsa		r.Osam after Levski		r.Dunav-v.Baykal		r.Dunav -Svishtov	
year	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**3**	**4**	**12**	**13**	**4**	**5**	**6**	**7**
2010	0.4	2.6			0.5	3.8	0.3	1.6	0.2	2.5	0.5	2.2	0.4	1.7	0.8	1.8
2011	0.2	2.83			0.5	4.3	0.4	2.2	0.5	2.9	0.3	2.8	0.04	1.44	0.82	1.9
2012	0.57	3.93			1.82	4.91	0.52	1.94	1.07	2.02	1.13	2.6	0.68	2.35	0.35	2.2
2013	0.17	3.4	1.17	3.61	2.08	4.6	1.06	1.79	1.3	4.92	1.4	2.28	0.53	1.88	0.48	2.33
2014	0.75	3.6	1.5	3.5	1.2	6	0.32	2.3	0.42	3.6	0.34	2.8	0.85	1.64	0.63	1.9
2015	0.25	2.65	1.4	3.05	2.2	4.5	1.06	2.3	1.8	3.5	1.8	3.1	0.6	1.66	0.6	1.8
2016	1.16	2.87	1.19	3.56	2.67	5.8	1.62	1.62	2.1	2.1	1.8	1.8	0.9	1.62	0.27	2.4
2017	1.6	2.09	1.67	1.67	0.89	4.23	0.14	1.96	2.6	3.3	1.54	2.62	0.3	1.8	0.42	4.5

Table 8 presents data on the nitrate content (nitrate nitrogen) in the Iskar, Vit, Osam and Danube rivers. The maximum values for nitrate nitrogen for the period 2010-2017 at the points at the mouths of the three rivers are as follows: Iskar river (Gigen village point) – 3.93 mg/L, Vit river (Gulyantsi point) – 5.8 mg/L, Osam river (Cherkovitsa village point) – 4.92 mg/L. For the indicated points for the Danube river, the maximum values for nitrate nitrogen are as follows: the village of Baikal - 2.35 mg/L and for the point after the town of Svishtov - 4.5 mg/L. These data indicate that the above-mentioned rivers contain significantly lower amounts of nitrates than the concentrations in the contaminated groundwater sources, suggesting that even in the presence of direct hydraulic connections, the water sources are not at risk of increased contamination from the rivers.

VI. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS:

1. In the Pleven region, public water supply is provided for all settlements, as a water supply infrastructure, it was mainly built in the last 4-5 decades and is operated by the state water supply company "W&S" Ltd. Pleven. In most cases, the basic infrastructure is planned and built to meet the needs of individual settlements. The construction of larger water supply systems for the needs of neighboring settlements is relatively rare.
2. Public water supply in the district is mainly provided by ground water belonging to the first aquifer, which is why water sources are highly vulnerable to contamination from the earth's surface. Only a few settlements, including the regional center of Pleven, additionally use flowing surface water captured in the neighboring Loveska region.
3. The main European recurements are implemented in the Bulgarian legislation documents related to the protection of the environment and the health of the population, including those on the quality of drinking water. The rules for Good Agricultural Practice have been introduced with a view to reducing the pollution of natural waters with nitrates from agricultural sources. In the Pleven region, like the other 10 regions in Northern Bulgaria, intensive agriculture (grain production) is practiced, which requires nitrogen fertilization.
4. For research, an 8-year period in 17 out of a total of 123 settlements in the district is recorded high nitrate content in drinking water. In 8 of them, water is supplied with persistently high annual average values of nitrates above 50 mg/L. In the remaining 9 settlements (Table 3), the exposure of the population to excessive concentrations of nitrates is episodic (only in certain seasons or years of the period):
    - The highest average values for the period were found in the village of Gigen and the village of Iskar (150.7 mg/L) and the town of Koinare (106.2 mg/L). In the mentioned 2 settlements live more than 2/3 (5976 inhabitants) of the total population in the group of the eight most affected settlements (8617 inhabitants), as well as 2/3 of the most sensitive group up to 1 year of age (114 out of a total of 151 children - Table 3).
    - The total population in the 17 settlements permanently or episodically exposed to nitrates is 16,085 inhabitants, which is 5.95% of the population of the district (269,752 inhabitants).
5. Most often, gaps are registered related to the practical implementation of the normative requirements that have been adopted declaratively, but for various reasons are not implemented and controlled. The presence of established WPZs was found in only about 1/10 of the drinking water sources in the district (66 WPZs out of a total of about 500 individual water sources);
6. In terms of preventing the contamination of drinking water in In Bulgarian legislation, Regulation No. 3/2000 on WPZs around water sources occupies a key place. There were no cases of formally set specific requirements or recommendations to the owners and users of agricultural lands on the territory of the established WPZs, including the most heavily contaminated water sources.
7. No cases of significant contamination of groundwater with nitrates as a result of wastewater discharges from animal farms, compromised fertilizer storage facilities, improper seasonal application of artificial fertilization, or other inherent agricultural activities.

8. A spatial analysis was carried out in a GIS environment of the most heavily contaminated villages nitrate water sources - the village of Gigen, the village of Iskar and the town of Koinare. This type of analysis is necessary for a comprehensive assessment of the combined effect of a number of factors determining the degree of nitrate pollution, such as the area of the watershed, the slope of the terrain around the water source, the formed accumulation flows, the distance of the water source from the pour point, the influence of soils and the type of land use around the specific water sources.

9. On the basis of the conducted complex analyses, concrete proposals were made for activities in two of the water supply systems (for the villages of Gigen, Iskar and for the town of Koinare), selected according to the following criteria:

- The highest degree of contamination of drinking water – average value of nitrates over 100 mg/L;
- The largest number of population exposed to nitrates with drinking water, namely 2/3 of the total population of the 8 settlements with the highest average values of nitrates;

10. The most rational solution for improving the quality of nitrates the supplied drinking water for the village of Gigen and the village of Iskar would be the construction of additional infrastructure to bring water from the operating wells along the Danube to the villages of Zagrazhden, Somovit and/or Kreta and subsequent mixing with the water of the functioning wells for the village of Gigen.

11. For the water source of the town of Koinare, we offer alternative solutions in depending on the conclusion of a professional financial and economic analysis, of the costs of the following activities:

- drilling for a new water source of GWB No. BG1G000N1BP036
- construction of a drinking water treatment plant with a denitrifying stage, a successful practice applied in the last 2-3 decades in EU countries (Austria, Niderland, Germany, etc.).

VII. RECOMMENDATIONS

1. Recommendations to “W&S” Ltd. Pleven

- Intensify activities to establish WPZs around ground drinking water sources, with priority those with the highest degree of contamination with nitrates and water supply systems, for the settlements with the largest number of inhabitants and relative share of exposed infants and young children.

- Application of spatial modeling through GIS to predict the degree of migration of nitrates from the soil to the groundwater during the construction of new water sources or in the process of establishment of WPZs for already built ones.

- To reduce the content of nitrates in the water supply system of the villages of Gigen and Iskar, we recommend discussing the option of diluting water from the functioning water source of the village of Gigen with water from some of the nearest water sources with low concentrations of nitrates used for water supply to the villages of Zagrazhden, Kreta and Somovit, fed by the same GWB.

- We recommend for the city of Koinare to choose a solution based on reliable hydro-geological data for a guaranteed sufficient flow rate of the water reserves of GWB No. BG1G000N1BP036, presented in the city's land. If, as a result of the relevant professional technical-economic analysis, it turns out that this proposal is not expedient, the possibility of applying an effective method for biological denitrification could be discussed.

2. Recommendation to the Ministry of Health and RHI-Pleven:

- In order to obtain more reliable information about the influence of precipitation on the migration of nitrates, the monitoring of the most heavily contaminated water sources should be conducted monthly, and not seasonally as it is at the moment.

VII. CONTRIBUTIONS

In the present work, a new modern approach for predicting the pollution of water sources with nitrates from agricultural activities is applied. This approach is based on spatial analysis in a GIS environment around specific water sources capturing shallow groundwater (first aquifer). The analysis includes the generation of web maps carrying information about the location of the water sources in space and in relation to other objects on the earth's surface - determination of the area and boundaries of the watershed around the ground water sources, definition of the accumulation flows, description of the relief and the type of land use in the watershed, etc. It is appropriate to apply this approach in all cases in the initial assessment of the long-term reliability of new water sources in relation to the possible contamination of the first aquifer with nitrates from agricultural sources.

The application of complex analyzes in a GIS environment, which approach is in continuous development and improvement, would help the experts in the selection of effective measures to overcome the most common problem in the public water supply in Bulgaria - the contamination of groundwater with nitrates from agricultural and other activities**.**

VIII. SCIENTIFIC MESSAGES AND PUBLICATIONS RELATED TO THE DISSERTATION

Full-Text publications in Scientific Journals:

1. E.K. Bankova, Modern methods and technologies for denitrification of drinking water, Jubilee scientific conference with international participation, "New approaches in public health and health policy" dedicated to 15 years since the establishment of the Faculty of Public Health, Pleven, 2020: reports, 2020, Publishing Center-MU-Pleven, pp. 88-94. ISBN - 978-954-756-254-7.

2.Emilia K. Bankova, Assessment of the measures implemented in Bulgarian legislation to reduce the content of nitrates in groundwater used for public water supply, J Biomed Clin Res Volume 16 Number 1, 2023,pp.44-54

3.Emilia K. Bankova, Kosta R.Vasilev, Diyana P.Zlatanova, Ivan T.Traykov, Milena G.Yancheva-Stoycheva, Vanya A.Birdanova, Tsvetelina G.Vitkova, Nitrate pollution prediction of shallow groundwater sources generated by computer programs integrated in GIS,– will be printed in December issue (2024, Vol. 16, Issue 2) of the international scientific journal "Ecologia Balkanica", indexed is Scopus (Q4) and Web of Science.

Scientific reports presented at conferences:

1. M Stoynovska, E Bankova, K Vasilev, I Atanasov, Tz Vitkova, N Statev, Application in Bulgaria of Directive 98/83/EC on the quality of water intended for human consumption, 11th European Public Health Conference, Winds of Change towards new ways of improving public health in Europe, 28 Novemler – 1 December 2018, LJUBLIANA. European Journal of Public Health 2018, volume 28, Suppl. 4, p.430, IF =2.782.

2. Emilia Bankova, Kosta Vasilev, Mariyana Stoynovska, Tsvetelina Vitkova, Ivelina Ruseva, Nikolai Statev, Nitrate content in the drinking water of Pleven region, 22nd Balkan Medical Days, 22èmes Journées Médicales des Balkanique,26-29 September 2019, Malpas Hotel , Kyrenia – Cyprus

3. Emilia Bankova, Kosta Vasilev, Evgenya Burzashka, Mariyana Stoinovska, Kristina Yosifcheva, Permanent deviations in the quality of drinking water in the Pleven region and the possible effects on the health of the population, National Conference on Clinical Toxicology, October 17-19, 2019, Varna, abstracts book ISBN 978-619-221-226-1, p.46

4. Emilia K. Bankova, Kosta R. Vasilev, Mariyana R. Stoynovska, Tsvetelina G.Vitkova, Ivelina R. Drambozova, Nikolai K. Statev „The nitrate content in drinking water of Pleven region and impact on vulnerable population", JUBILEE SCIENTIFIC CONFERENCE 45 years Medical University – Pleven, Pleven, 31.10-2.11.2019

5. Emilia Bankova, Kosta Vasilev, Ivalin Georgiev, Suzana Gafurova, "Excessive content of nitrates in the drinking water of the Pleven region and the need for measures according to the health consequences of increased exposure of the population", National conference on clinical toxicology with international participation on the topic: "Toxicology today" 02 - 04 June 2022, MU - Pleven. Collection of summaries, p. 15, ISBN:978-954-756-288-2

6. Bankova, E., K.Vasilev, V.Birdanova,Tsv. Votkova, D.Zlatanova, I.Traykov, Assessment of ground water sources for small settlements in the Pleven region with a view to ensuring standard drinking water according to the nitrate indicator VI National Conference of the Bulgarian scientific society of public health „Public health:challenges for the health system", Medical university - Pleven, 26 - 27 may, 2023, J Biomed Clin Res, 16(1), p.63

7. Manoleva Nikol, Traykov Ivan, Bankova Emilia, Effectiveness of point-of-use (POU) systems for removal of contaminants from water, abstract book p.82, INTERNATIONAL CONFERENCE “Kliment's Days 2023 - 60 Years Faculty of Biology“,9-11 November, Sofia

Participation in scientific projects related to the topic of the dissertation:

-Project № 12/2022, topic: „Evaluation on Groundwater bodies in Pleven region used for extraction of drinking water , in view of their vulnerability to nitrate pollution from agricultural sources.“, Medical University - Pleven, Faculty of Public Health, Department of Hygiene, Medical Ecology, Occupational Diseases and Disaster medicine, project manager - Assoc. Professor Kosta Raykov Vassilev, MD, PhD

-Project № 20/2024, тема: „Optimizing Nitrate Groundwater Pollution Predictions Using Modern GIS Tools”, Medical University - Pleven, Faculty of Public Health, Department of Hygiene, Medical Ecology, Occupational Diseases and Disaster medicine, project manager - Assoc. Professor Kosta Raykov Vassilev, MD, PhD

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