A Digital Groundwater Map Of Bulgaria In 1:500 000 Scale – Objectives And Methodological Approach

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Abstract

The present groundwater map of Bulgaria is intended for a wide range of users - hydrogeologists, non-professionals in the field of hydrogeology, investors, students, etc. who wish to get a general idea of the distribution and type of main groundwater and mineral water reservoirs in Bulgaria. Four classes according to groundwater productivity and four subclasses depending on the porosity type of water-bearing rocks are used to categorise the hydrogeological formations: major aquifers in class A, major aquifers in class B, minor aquifers in class C, and non-aquifers in class D; porous aquifers in subclass 1, fractured aquifers in subclass 2, fractured-karst aquifers in subclass 3, and porous-karst aquifers in subclass 4. The separate classes can be identified by the different letter indices and colours, while the separate subclasses by the different numerical indices and patterns. It also includes only the most significant groundwater springs and mineral water sources exclusively property of the state. The map has been prepared as a digital model in GIS - MapInfo which makes it particularly easy to use and update by computer data base processing.

Key-words: groundwater, map, GIS

Introduction

The present groundwater map of Bulgaria on a scale of 1:500,000 is intended for a wide range of users - hydrogeologists, non-professionals in the field of hydrogeology, investors, students, etc. who wish to get a general idea of the distribution and type of main groundwater and mineral water reservoirs in Bulgaria.

The map can be used in different ways depending on the interests of the user. For those wishing to find the location of the most productive aquifers in Bulgaria, a look at the map is enough since the differences between the separate aquifers are given in colours. A closer look at the map will reveal the lithological type of the water-bearing formations, the location of the basic groundwater springs and mineral water reservoirs, the boundaries of the hydrogeological regions and the areas for basin water management. A further detailed examination of the map with the help of the explanatory note will enable the user to discover the stratigraphic levels and names of the separate aquifers, their distribution and finally, the official litho-stratigraphic units to which these are associated.

The map has been prepared not only as a hard copy representation but also as a digital model in GIS - MapInfo which makes it particularly easy to use and update by computer data base processing.

As a first attempt to create a hydrogeological map intended for a wide range of users, this groundwater map of Bulgaria certainly has its drawbacks. The authors will be grateful to all colleagues and users who send their critical remarks and recommendations for improving the map's quality.

Hydrogeological regions in Bulgaria

According to the hydrogeological division of Bulgaria (Antonov and Danchev, 1981), the territory of Bulgaria is divided into three hydrogeological regions: Moesian, Balkanide and Rila-Rhodope. The boundaries of the hydrogeological regions are shown in Fig. 1. These regions are characterized by the following hydrogeologically specific features.

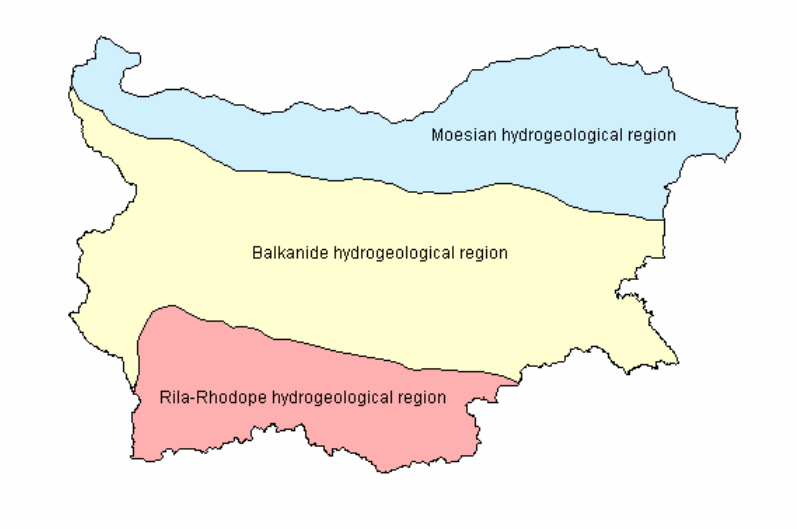

Figure 1. Hydrogeological regions in Bulgaria

Moesian hydrogeological region

The Moesian hydrogeological region coincides in area with the geomorphological region of the Danube hilly plain and the tectonic region of the Moesian plate. The North-Fore-Balkan fault serves as the southern boundary of the region. Three first-order morphotectonic structures (regions) have formed as a result of continuous epirogenic movements: Lom-Pleven depression - on the west; North-Bulgarian uplift - in the middle; Varna depression - on the east.

The region is generally characterized by the following features:

- The level position of the aquifers and complexes in the Mesozoic-Cainozoic cover, the largest number of aquifers being in the two depressions.
- Vertical hydrodynamic zoning of the groundwater. Three zones can be identified:

(i) Upper zone with an active water exchange and fresh unconfined and confined waters from the infiltration genetic cycle.

(ii) Middle zone with slow water exchange, higher mineralization and water temperature. The waters are confined and of mixed genesis - old marine and infiltration waters.

(iii) Lower zone - there is practically no water exchange, the waters are highly mineralised (from 50 to over 200 g/l) and the water temperature is high. By origin the waters are mainly from the sedimentogenic cycle (Sinian and epigenetic), which have undergone considerable metamorphosis under conditions of stagnant water regime and great depth. The Triassic and basement waters fall into this zone.

- There is a hydraulic connection between the aquifers and complexes at certain points along the tectonic fault lines, which are otherwise well isolated from each other (with the exception of the sections with hydrogeological windows).
- Considerable area distribution of the Pre-Quaternary aquifers, some of them (the Malm-Valanginian and, with a few exceptions, the Middle Triassic one) having pervasive occurrence.

Balkanide hydrogeological region

The Balkanide hydrogeological region comprises the area between the Rila-Rhodope region on the south and the Moesian region on the north. Both its boundaries are deep faults. The complex tectonic structure of the Balkanide region, its complex relief forms and deeply drained mountain folded systems create very specific conditions of ground water occurrence, formation, regime and dynamics.

The Balkanide hydrogeological region is generally characterized by the following features:

- Presence of numerous fold anticline and syncline structures with separate aquifers as part of these. In some cases the fold structures are isolated from each other (there is no hydraulic connection) and occur as separate groundwater reservoirs, whereas in other cases they are hydraulically connected, i.e. they form a common reservoir, the water flowing from one hydrogeological formation to another (the Fore-Balkan region, the western part of the Balkan, etc.).

- Wide distribution of graben structures (superimposed depressions) filled mainly with Neogenic and Quaternary depositions. In hydrogeological terms, these superimposed depressions (kettles) are separate reservoirs with considerable resources of fresh unconfined and confined ground water. These are the Upper Thracian depression, Sofia kettle, Sliven-Straldja kettle, Bourgas depression, etc.
- Wide distribution of connate waters with shallow circulation, connected with zones of regional exogenic fracturing.
- Lack of highly mineralised waters. The waters are generally fresh. Low mineralised waters with a total mineralisation of 1 to 5 g/l occur only in some places of the Fore-Balkan, Sofia kettle, Maritsa river basin, etc.

Rila-Rhodope hydrogeological region

The Rila-Rhodope region comprises the Rhodope, Rila, Pirin, Ograzhden and Malashevska mountain massifs. The region is deeply drained by the river valley system whose density is over 2 km/km^2. Rocks of Archaic, Proterozoic, Paleozoic, Paleogene, Neogenic and Quaternary age participate in the structure of the Rila-Rhodope region.

The Archaic rocks are represented by varieties of gneiss, gneiss-schist, amphibolite, etc. The Proterozoic complex is represented by six formations and is most widely distributed. The Paleozoic rocks are the South-Bulgarian granites which are widely distributed in the cores of the anticline structures - horsts and the Strouma diorite formation.

The Paleogene rocks are distributed in the superimposed depressions and graben structures. The rock complex contains a wide variety of rocks - sedimentary, volcano-sedimentary and volcanic. The volcanism is most strongly manifested during the Oligocene. The Pliocene and Quaternary rocks occur in the youngest graben structures (kettles).

There are a number of anticline structures in the Archaic and Proterozoic rock complexes whose formation is associated with the intrusion and uplifting of the Paleogene intrusive bodies - granitoids. The major anticline structures are: Middle Rhodope, South Rhodope, Pirin horst-anticline, etc. Amidst the anticlines are located corresponding synclines. The fault tectonics is widely manifested in this region. It relates not only to the formation of the deep graben structures but also to the occurrence of fresh thermal waters of the fractured confined water system.

The Rila-Rhodope hydrogeological region is generally characterized by the following features:

- All ground waters are fresh.
- The connate waters are most widely distributed and according to circulation conditions are subdivided into shallow and deep waters. The deep fractured zones are connected to a large number of mineral water reservoirs.
- Separate karst water reservoirs of considerable water resources have formed in the karsted Proterozoic marbles.
- The kettle grabens are separate reservoirs of unconfined and confined ground water.

Methodology of map preparation

In view of the scale and main purpose of the map, it has been prepared in such a way as to meet maximally the following requirements:

- be simplified with respect to the geological and hydrogeological information but reflect sufficiently and completely the regional distribution of the main hydrogeological formations and natural groundwater reservoirs;
- be easily readable, the differences being given in colours and simplified graphical patterns without overloading the map field with information items;
- give an idea of all significant mineral water reservoirs in Bulgaria;
- have a simplified legend which is familiar to a wide range of readers;
- have a catalog of all significant hydrogeological formations by which the name, class, distribution and aquifer can be identified for each hydrogeological object on the map.

Various sources of hydrogeological information were used in completing the data base and designing the map model. These sources can be arranged by a usability criterion as follows:

- Hydrogeological Map prepared by Hr.Antonov & D.Danchev as well as the monograph Ground Waters In Bulgaria (1980) - on the basis of which the boundaries of most hydrogeological

formations on the territory of Bulgaria have been outlined and the main cold and thermal groundwater springs have been designated;

- Geological Map Of Bulgaria on a scale of 1:500,000 (1989) and Tectonic Map Of Bulgaria on a scale of 1:500,000 (1976) - on the basis of which the boundaries and geological indices of the outcropping and deep-seated hydrogeological formations have been specified;
- Geological Map Of Bulgaria on a scale of 1:100,000 (separate map sheets) - on the basis of which a hydrogeological classification has been created of the sedimentary formations in the Moesian plate and the Upper-Thracian graben which are a basic groundwater reservoir. On the basis of these map sheets generalised vertical hydrogeological diagrams have been plotted which show the occurrence of the different aquifers in cross section;
- Hydrothermal Map Of Bulgaria on a scale of 1:500,000 (1999) prepared by P.Petrov et al, on the basis of which a number of new mineral water reservoirs (springs and wells) have been added;
- Publications And Archive Sources from the National Geofund at the Ministry of Environment and Waters - on the basis of which the classes of some of the basic hydrogeological formations with respect to groundwater productivity have been specified.

Classification of hydrogeological formations

The term “hydrogeological formation” is widely used in this text. This term designates such geological formations (lithostratigraphic units) which are groundwater reservoirs and have some hydrogeological significance. According to their productivity, the hydrogeological formations can be aquiferous (water-bearing horizon, water-bearing complex, aquiferous fractured zone, karst basin) or non-aquiferous (geological bodies of very low permeability and insignificant groundwater resources). Synonyms of the term “aquiferous formation” are the terms “aquifer” or “groundwater reservoir”.

Four classes according to groundwater productivity and four subclasses depending on the porosity type of water-bearing rocks are used to categorise the hydrogeological formations within the boundaries of the separate regions (Fig. 1).

The criteria for classifying the hydrogeological formations by productivity are given in Table 1. The following classes are used:

- major aquifers in class A and B;
- minor aquifers in class C; and
- non-aquifers in class D.

Table 1. Classification Of Hydrogeological Formation By Water Productivity

Class of hydrogeological formation	Index	Aquifer transmissivity m^2/d	Specific productivity of pumping wells (l/s)/m	Groundwater discharge module $(l/s)/km^2$
Major aquifer	A	>500	> 4	> 5
Major aquifer	B	250 - 500	2 - 4	2 - 5
Minor aquifer	C	10 - 250	0.1 - 2	1 - 2
Non-aquifer	D	< 10	<0.1	< 1

Table 2 presents the criteria for classifying the hydrogeological formations by porosity type of water-bearing rocks. The following subclasses are used:

- porous aquifers in subclass 1;
- fractured aquifers in subclass 2;
- fractured-karst aquifers in subclass 3; and
- porous-karst aquifers in subclass 4.

Table 2. Classification Of Hydrogeological Formations By Type Of Predominant Rock Openings

Subcalass of hydrogeological formation	Index	Type of predominant rock openings	Litological type of water-bearing rocks
Porous	1	Pores	Non-consolidated granular deposits: sands, gravels, conglomerates etc.
Fractured	2	Fissures	Fissured silicate rocks: sandstones, ryolites, andesites etc.
Fractured-karstified	3	Fissures and/or caverns	Fissured and/or cavernous carbonate rocks: limestones, dolomites, marbles etc.
Porous-karstified	4	Pores and caverns	Alternation between sandy layers and cavernous carbonate rocks

The separate classes can be identified by the different letter indices and colours, while the separate subclasses by the different numerical indices and patterns. The symbols are given in Fig. 2.

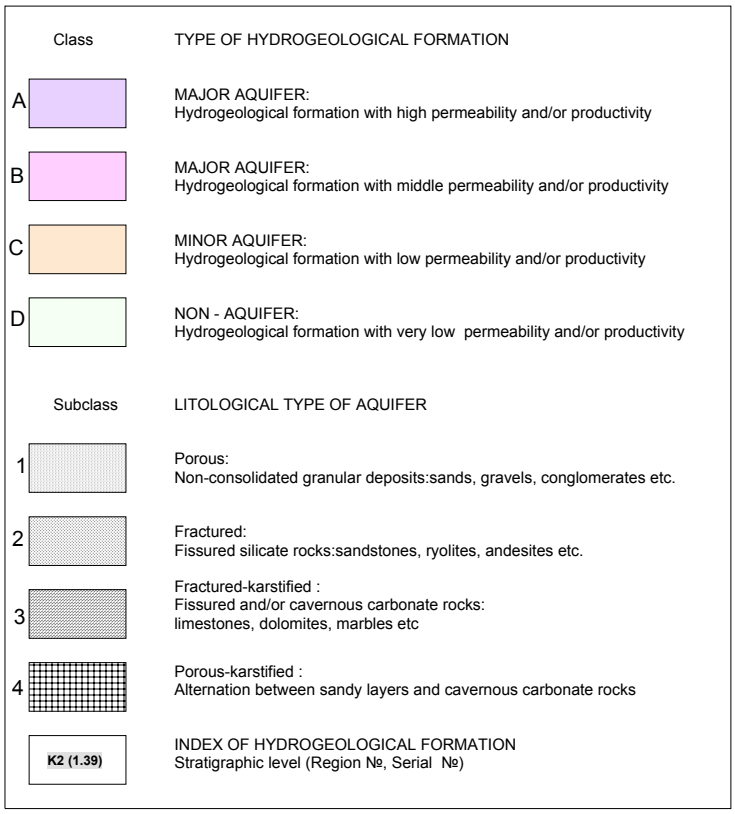

Figure 2. Classes, subclasses and indexes of hydrogeological formations

The boundaries of the aquiferous formations (classes A, B and C) have been outlined on the basis of the water-bearing rock outcrops on the Earth's surface or their occurrence immediately beneath the Quaternary cover of low permeable clays and loess.

The areas of local outcrop of aquiferous formations on the Earth's surface (in the form of small spots with an area of up to 10 km^2) are neglected, except for the cases when these are located within the boundaries of separate karst basins. Thus the map is cleared up of information items of no particular significance for the regional characteristics of the hydrogeological conditions.

The boundaries of the practically non-aquiferous formations (class D) are assumed to coincide with the areas of distribution of connate ground water with a out-flow module $M_n < 1$ (l/s)/km^2. Such assumption is fully acceptable since a similar type of connate waters are characteristic of regions of low groundwater resources.

Catalog of aquifers

The main purpose of the catalog is to identify the class, subclass, stratigraphic level and name of each hydrogeological object (aquifer) included in the groundwater map. Furthermore, the catalog enables the user to understand its distribution and the name of the official lithostratigraphic formation to which the particular hydrogeological object is associated.

For the purpose, each aquifer is given an identification index composed of two digits separated with a point. The first digit shows the number of the region in the catalog, the second one - the serial number of the aquifer in the same region. The numbering of the hydrogeological regions is made as follows: 1 - Moesian hydrogeological region; 2 - Balkanide hydrogeological region; 3 - Rila-Rhodope hydrogeological region. The aquifers in the separate regions are arranged (sorted) in a descending order according to the following three characteristics - class, subclass and stratigraphic level. The aquifers of class A, subclass 1 and stratigraphic level Q (Quaternary) have the lowest serial numbers in a given region. The aquifers of class C, subclass 4 and stratigraphic levels of the lowest stages in the chronostratigraphic table have the highest serial numbers.

The water-bearing horizons (WBH) and water-bearing complexes (WBC) are named according to stratigraphic level, e.g. Paleogene WBH or Neogene-Quaternary WBC. An exception to this rule are only the aquifers (water-bearibg horizons) in the river pans which are named as alluvial, e.g. Alluvial WBH on the River Danube. The aquiferous fractured zones (AFZ) and karst basins (KB) are named according to a geographical feature, e.g. Vitosha AFZ or Iskrets KB.

The designation of the separate aquifers preserves the popular names in the Bulgarian hydrogeological literature such as: Malm-Valanginian WBH, Nastan-Trigrad KB, Pirin AFZ, etc. Many names of aquifers and water complexes are given for the first time due to the lack of approved and generally accepted names of the respective formations. The same applies to a number of separate karst basins or aquiferous fractured zones which have so far remained nameless.

Springs and mineral water reservoirs

The map includes all significant fresh groundwater springs having an average flow rate higher than 1 l/s. The symbols shown in Fig. 3 are used to identify the springs of comparatively stable discharge ($Q_{max}/Q_{min} < 10$). A separate symbol designates the springs of highly variable discharge ($Q_{max}/Q_{min} > 10$) for which there are no data on the average flow rate.

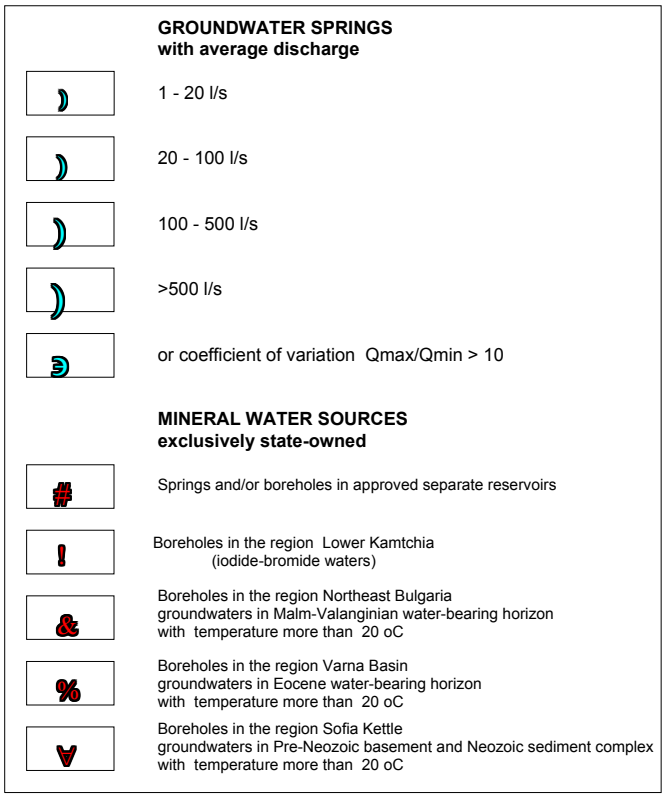

Figure 3. Groundwater springs and mineral water sources symbols

Of all mineral water reservoirs, the map includes only those which are exclusively state-owned. The symbols shown in Fig. 3 are used to distinguish the separate reservoirs (localised at separate springs and wells) from the mineral water areas without approved boundaries. A numerical index is added to each separate reservoir by which its name can easily be identified.

Digital map model

This map has been prepared as a digital model for computer use. The MapInfo software has been used as a basic GIS. The digital map model contains the following information layers:

- Borders of the Republic of Bulgaria
- Boundaries between hydrogeological regions
- Boundaries between basins for water management
- Main rivers and surface water reservoirs
- Built-up areas up to the level of a municipal centre
- Hydrogeological formations:

(i) Major aquifers in class A - subclasses from 1 to 4;
(ii) Major aquifers in class B - subclasses from 1 to 4;
(iii) Minor aquifers in class C - subclasses from 1 to 4;
(iv) Non-aquifers in class D

- Index of aquifers
- Groundwater springs
- Mineral water reservoirs, exclusively state-owned
- Five layers related to the map legend

The digital model is accompanied by an explanatory note and 23 appendices in WORD and EXCELL. It can be supplemented, updated and used as a basis for generating small-scale thematic maps such as: a karst groundwater map, a mineral water reservoir map, a ground water vulnerability map, etc.

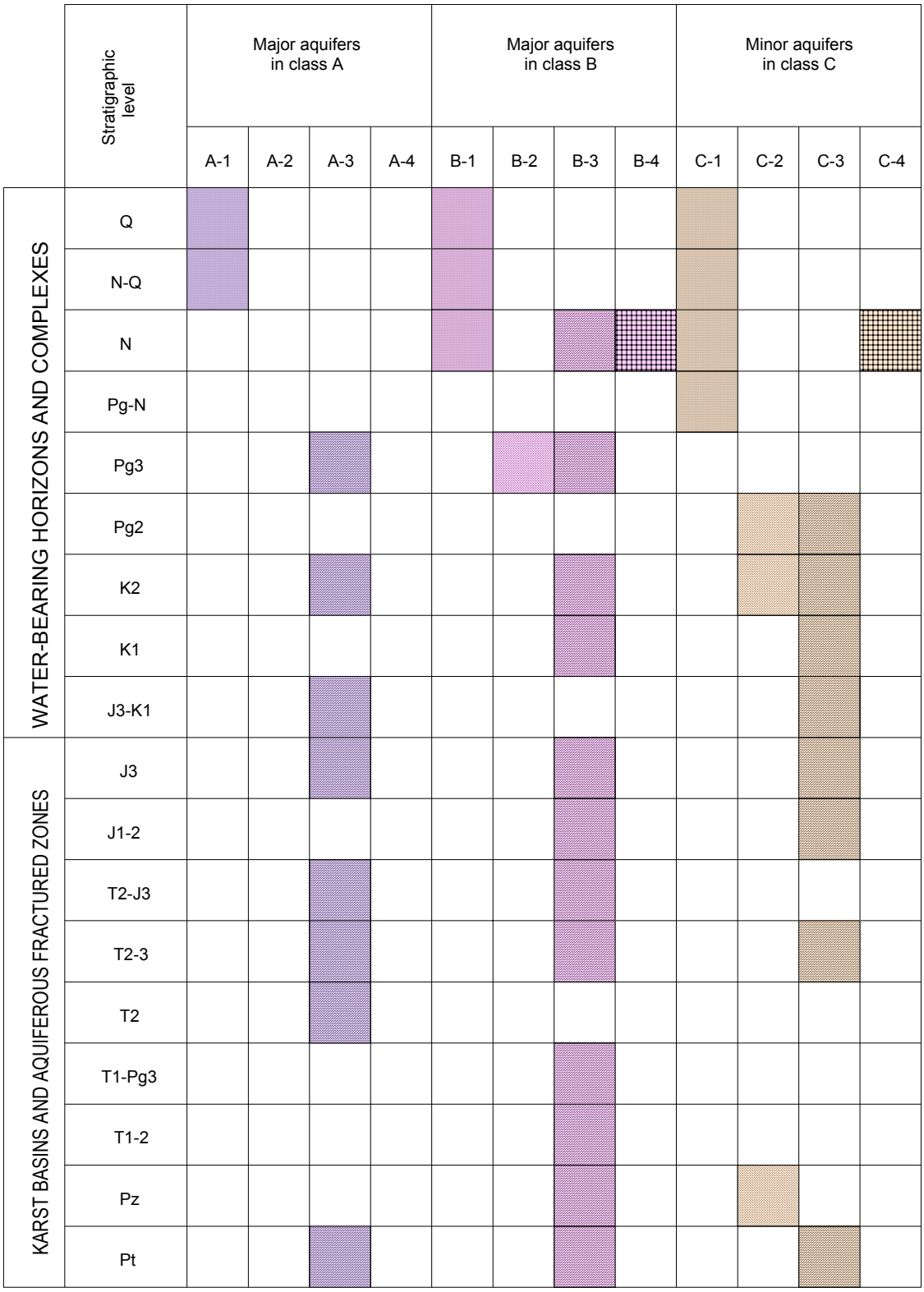

Figure 4. Distribution of hydrogeological formations by stratigraphical levels in depth

A general view of the hydrogeological map of Bulgaria is presented in Fig. 5. All layers of digital map are overlayed in the figure.

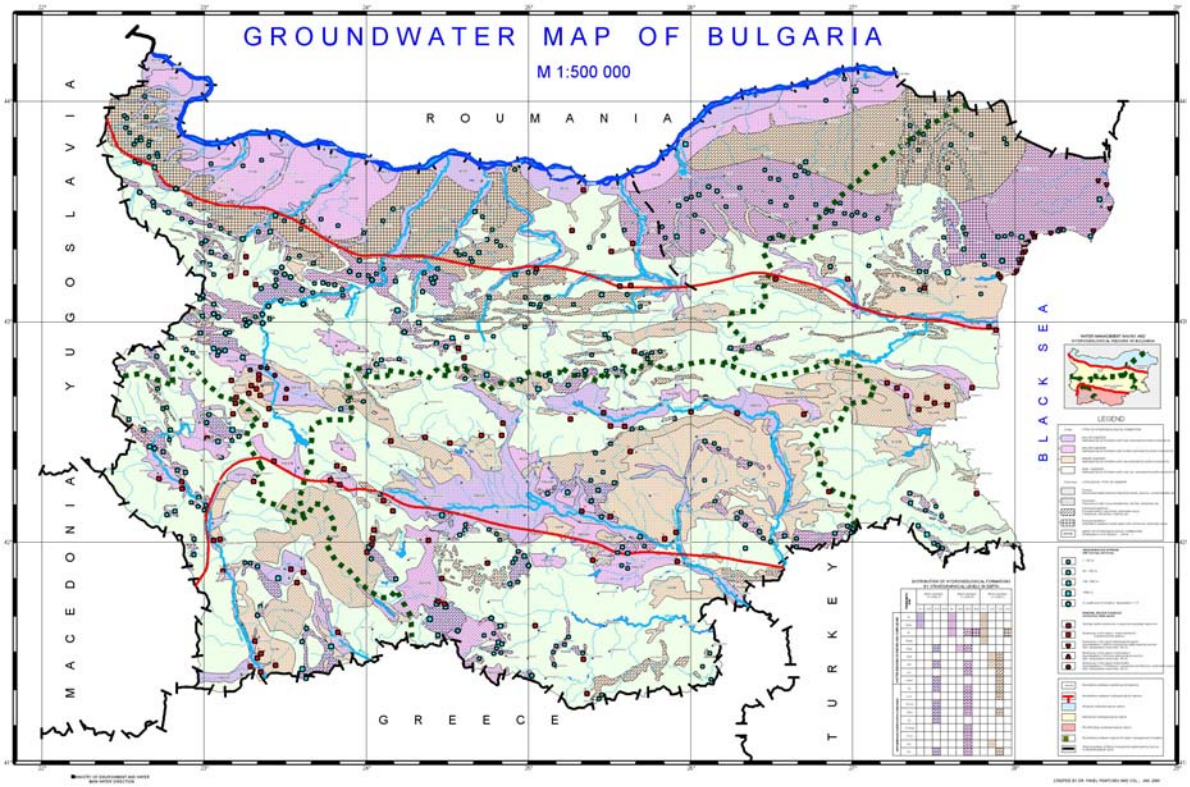

Figure 5. Groundwater map of Bulgaria on a scale of 1:500,000.

A more detailed view of the model is depicted in Fig. 6. The exact boundaries of the hydrogeological formations, groundwater springs and mineral water sources of the North-East part of Moesian hydrogeological region of Bulgaria are shown.

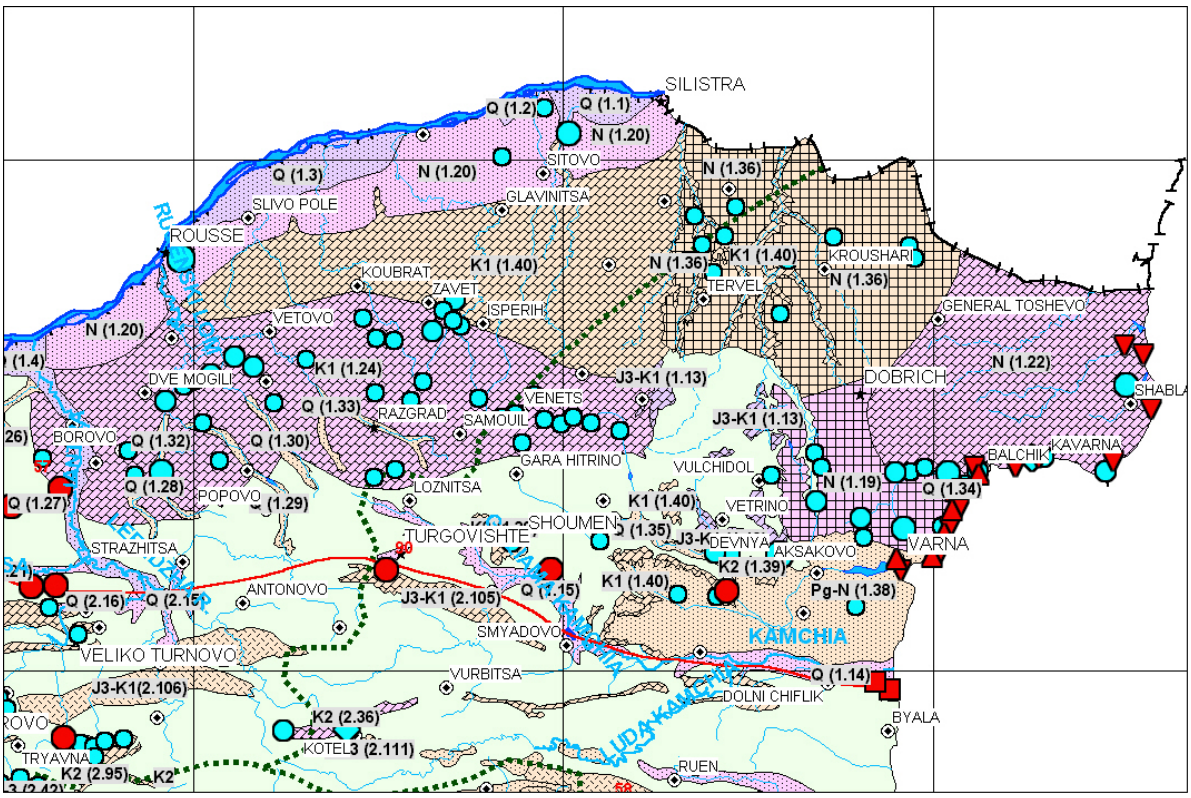

Figure 6. North-East Part Of Moesian Hydrogeological Region Of Bulgaria (close look).