Assessing the ground waters of Bulgaria using a Water Quality Index

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Abstract. The study focuses on the quality of shallow groundwater in Bulgaria based on the content of major ions. To be safe for drinking purposes, their concentrations must not exceed the respective thresholds. The groundwater quality is assessed in terms of health hazard by a groundwater quality index (GWQI or WQI), and the respective map is presented. The results show that for the territory of Bulgaria, this index varies from 13 to 92. The highest values of this index (related to health hazard) are typical for the lower hypsometric zone of the country. The shallow groundwater in the zone of active water exchange is distributed as follows: waters of excellent quality, waters of good quality, waters of poor quality, and waters of very poor quality, covering 3%, 39%, 22%, and 31% of the whole area of the country, respectively. In this study, no estimates have been made for 5% of the territory of Bulgaria, which is characterized by the presence of very hard groundwater.

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INTRODUCTION

In nature, water moves in a continuous cycle. During this cycle, various substances dissolve, and therefore its composition is complex. When it falls on the earth's surface, rainwater increases its mineralization by dissolving a number of substances – both organic and inorganic, determining the quality of groundwater, and the possibilities for its usage for various purposes. The Regulation on the Quality of Drinking Water is a provision that describes the desired condition of any water intended for drinking and domestic use. Drinking water can be defined as water for both drinking and domestic use – either in its natural state or after the necessary processing, and is intended for drinking, food preparation and other household usage, regardless of its origin.

Thus, in order to be drinkable, water must meet the values of the indicators, as specified by the Regulation, and be safe and clean (*i.e.*, harmless to human health). It should be mentioned that, if the content of individual substances in the water does not exceed the permissible upper limits set by standards, this still does not mean that the water can be

used for drinking and domestic usage. Water quality can also deteriorate by all the adverse effects of substances and impurities, which are individually below the permissible concentrations. This requires the creation of an integrated groundwater quality assessment tool.

It should be noted that the present research makes an initial integrated regional assessment of the situation regarding the content of macro-components in the shallow groundwater of Bulgaria. The objective of this study is to investigate the ground waters from the hypergenic zone on the territory of Bulgaria. And the overall aim is to present an integrated qualitative assessment of their chemical status in terms of their major ion content.

DESCRIPTION OF THE AREA

The study area includes the whole territory of Bulgaria, which is approximately 111,000 km². The country is located in the south-east corner of Europe, occupying the eastern part of the Balkan Peninsula. Bulgarian topography can be described as mostly

flat and hilly (about 70% of the area), with most plains located in the north and the south-east of the country. The average altitude of the country is about 470 m, and five types of elevation can be described: lowlands (0–200 m), plain-hilly (201–600 m), low-mountainous (601–1000 m), mid-mountainous (1001–1600 m), and alpine (1601–2925 m) (see Fig. 1). The climate in Bulgaria is moderately continental, with the maximum precipitation occurring in the months of May and June, and the minimum in February. The southernmost parts of the country fall into the continental-Mediterranean climatic zone, characterized by high precipitation values during the fall-winter season and severe droughts in the summer. The average rainfall varies from about 450–500 mm in some areas to 1,000–1,400 mm in

the higher mountainous regions (Koleva and Peneva, 1990). The average maximum long-term air temperature is +14 °C (measured in July and August), and the minimum is –3 °C (in January) (Kyuchukova, 1983).

Geological setting

Bulgaria has a very complex geological structure (Dabovski *et al.*, 2002), and widespread existence of varied rock formations with ages from the Precambrian to the Quaternary (Cheshitev *et al.*, 1989). These rocks possess various surface exposure and distribution, and present different types of filtration, media for the groundwater (pore, karst) and fissures (Antonov *et al.*, 1960) (Fig. 2). Quaternary

Fig. 1. Location of the study area and topographic map of Bulgaria.

Fig. 2. Hydrogeological map of Bulgaria (after Cheshitev and Kanchev, 1989). Legend: 1 – Distribution of Quaternary unconsolidated deposits with porous water; 2 – Surface deposits of Neogene and Paleogene water-saturated rock complexes with porous aquifers; 3 – Weathering and fracture zones in solid sedimentary rocks with fissured water; 4 – Volcanic and volcano-sedimentary rocks with fissured water; 5 – Intrusive rocks with fissured waters in areas of regional cracking; 6 – Metamorphic rocks with fissured water in areas of regional cracking; 7 – Karst and fissured-karst water in sedimentary rocks; 8 – Water bodies.

deposits, including deluvial, eolian and alluvial, occupy almost the entire northern part of the country, where loess cover is also widespread. The depth of the loess deposits decreases southwards, from about 40–50 m in close proximity to the Danube River to 3–5 m at the Fore-Balkan Mts (Minkov, 1968). According to their genesis, pre-Quaternary rocks in Bulgaria are magmatic (intrusive, effusive and pyroclastic), sedimentary and metamorphic.

Geological conditions play a major role in shaping the composition of groundwater, as well as in the rock-water interaction processes. According to their origin, mineralogical and petrographic composition, the rocks contain chemical components in different concentrations, which affect the natural chemical composition of groundwater. In other words, the composition of groundwater depends on both the characteristics of the rocks, with which the water has been (or presently is) in contact, and the

rock-water interaction. The processes of interaction between rocks and water have already been studied in the literature (*e.g.*, Malov, 2004; Elanqo and Kannan, 2007; Stoyanov, 2019).

Presently, there has been done much research regarding the quality of groundwater in Bulgaria, but most of it has been of local character, concerning only certain geographic areas and water bodies. Some data for the overall chemical composition of the various types of water on the territory of Bulgaria can be found in regional summaries, as well as in reference books (Lechev *et al.*, 1968; Stefanov, 1979). A number of processed results, including a compilation of different types of hydrochemical maps, were published by Kehajov (1968, 1970, 1972, 1978, 1979a, b, 1981, 1982, 1984a, b), and Kehajov *et al.* (2002). The publication regarding the role of the geological influences on the formation of the chemical composition of groundwater in Bulgaria was given by Gerginov *et al.* (2019).

The results of several monitoring observations and other hydrochemical studies, focused mainly on the ecological status of groundwater, have been summarized in the River Basin Management Plans, and can be seen on the websites of the Bulgarian Ministry of Environment and Waters and the Basin Directorates. As characteristic features of all previous studies, it can be concluded that they are all based on estimates of separate indicators and make no use of integrated results.

DATA USED IN THE STUDY

The data used in the present study for the macro ions in the groundwater from the hypergenic zone in Bulgaria was published by Kehajov (1968). The major ions making up the main part of the mineralization of fresh groundwater, and determining its geochemical appearance and suitability for various purposes, include the following: bicarbonates, sulfates, chlorides, calcium, magnesium, sodium and potassium (HCO_3^- , SO_4^{2-} , Cl^- , Ca^{2+} , Mg^{2+} , Na^+ and K^+). As already mentioned above, the data used herein (Table 1) for the average content of major ions in the groundwater was taken from Kehajov (1968). The average chemical composition was obtained from 2,016 analyses of water samples taken from different water points, such as springs, wells, drainages and boreholes, that are comparatively evenly distributed all over the territory of Bulgaria. For the purposes of this research, the total hardness is taken as the sum total of calcium and magnesium ions in meq/l, and the total mineralization is presented as the sum total of all ingredients in mg/l (Table 1). All data presented below was obtained by Kehajov (1968) and digitized by the author in GIS environment.

PHYSICAL-CHEMICAL PARAMETERS USED IN THE STUDY

From the analyses of the water samples performed by Kehajov (1968) of the water samples taken from groundwater in the hypergenic zone, the waters on the territory of Bulgaria can be divided into six categories by their total hardness and, for each category, the average macro-chemical composition can be determined. Accordingly, the groundwater of the country can be divided as follows: very soft water (3%); soft water (24%); moderately hard water (15%); rather hard water (22%); hard water (31%); and very hard water (5% of the whole studied area). The distribution of these categories on the territory of Bulgaria is shown in Fig. 3, from which it can

Table 1
Data used in the study area

Type of water	Parameters	Average value, mg/l	Average value, meq/l
Very soft water	Na+K, mg/l	9.2	0.400
	Ca, mg/l	16.7	0.833
	Mg, mg/l	5.3	0.436
	Cl, mg/l	5.7	0.161
	SO_4 , mg/l	12.3	0.256
	HCO_3 , mg/l	75	1.229
	TH, meq/l	1.3	1.269
	TDS, mg/l	124.2	0.400
Soft water	Na+K, mg/l	14.8	0.644
	Ca, mg/l	44	2.196
	Mg, mg/l	9.8	0.806
	Cl, mg/l	11.3	0.319
	SO_4 , mg/l	20.6	0.429
	HCO_3 , mg/l	177	2.901
	TH, meq/l	3.0	3.002
	TDS, mg/l	277.5	0.644
Moderately hard water	Na+K, mg/l	17.2	0.748
	Ca, mg/l	64.3	3.209
	Mg, mg/l	15.7	1.292
	Cl, mg/l	12.1	0.341
	SO_4 , mg/l	16.8	0.350
	HCO_3 , mg/l	278	4.556
	TH, meq/l	4.5	4.501
	TDS, mg/l	404.1	0.748
Rather hard water	Na+K, mg/l	19.6	0.853
	Ca, mg/l	84.2	4.202
	Mg, mg/l	21.9	1.802
	Cl, mg/l	16	0.451
	SO_4 , mg/l	14.4	0.300
	HCO_3 , mg/l	372	6.097
	TH, meq/l	6.0	6.004
	TDS, mg/l	528.1	0.853
Hard water	Na+K, mg/l	39.1	1.701
	Ca, mg/l	81.2	4.052
	Mg, mg/l	60.2	4.954
	Cl, mg/l	55	1.551
	SO_4 , mg/l	55.1	1.147
	HCO_3 , mg/l	488	7.998
	TH, meq/l	9.0	9.006
	TDS, mg/l	778.6	1.701

be seen that the total hardness of water decreases with the average altitude, and vice versa. The same trend applies to the total dissolved solids, i.e., the total dissolved solids in water increases with the decrease in the average altitude.

For the territory of Bulgaria, the concentrations of basic components found in groundwater have been found to vary widely (see Table 1, Figs 4–9). For instance, the hydrocarbonate content varies from 75 mg/l to 488 mg/l, and it has the most vari-

Fig. 3. Digitalized map showing the spatial distribution of the total water hardness for the study area, based on data of Kehajov (1968).

Fig. 4. Average groundwater chemistry in the study area (sodium and potassium).

Fig. 5. Average groundwater chemistry in the study area (calcium).

able anion concentration, followed by the presence of chlorides and sulphates. Chlorides vary from 5.7 mg/l to 55.0 mg/l, and sulphates vary from 12.3 mg/l to 55.1 mg/l. The main dominant cation is calcium, the concentration of which varies in the

range of 16.7 mg/l to 84.2 mg/l. Magnesium varies from 5.3 mg/l to 60.2 mg/l, and only in the hard groundwater does it dominate over calcium. The rapid increase in the concentration of major ions can be seen with any decrease in altitude, leading

Fig. 6. Average groundwater chemistry in the study area (magnesium).

Fig. 7. Average groundwater chemistry in the study area (chlorine).

Fig. 8. Average groundwater chemistry in the study area (sulphates).

Fig. 9. Average groundwater chemistry in the study area (bicarbonates).

Fig. 10. Dependency of the total hardness (TH) and total dissolved solids (TDS) versus average altitude above sea level.

to an increase in the total hardness and sum total of dissolved solids (Fig. 10). Therefore, the ground waters in question can be described as hydrocarbonate with predominant calcium cations.

CHEMICAL COMPOSITION AND TYPES OF GROUNDWATER

Piper diagram and Kurlov equation

Groundwater is essentially a solution of salts, and its chemical nature, like that of all solutions, is based upon the nature and proportion of the substances it contains. The chemical composition of ground waters, or their type, is represented by the Piper diagram (Piper, 1944) and according to Kurlov's criterion (Pentchev *et al.*, 1990). These diagrams are in fact classifications by means of combining their components.

Piper (1944) classified the water types and their hydrogeochemical appearance by plotting the distribution of major cations and anions that determine the geochemical type of groundwater.

Kurlov equation represents the type of groundwater by an equation, in which anions with concen-

trations above 5 eq% are written in a descending order in the numerator, and with concentrations above 5 eq% the cations are written in a descending order in the denominator. The name of the water type has been determined by the content of anions and cations in concentrations above 20 eq%.

Chadha diagram

The chart developed by Chadha (1999) gives an overall assessment of the main geochemical processes affecting the formation and composition of groundwater. The Chadha Diagram has been used to classify the various groundwater types and to identify the hydrochemical processes that control water composition. The diagram is a modified version of the Piper Diagram (Hamed *et al.*, 2010), in which both equilateral triangles have been omitted.

GROUNDWATER QUALITY ASSESSMENT METHODOLOGY

In practice, two approaches can be applied when assessing water quality by its physicochemical indicators: a differentiated one and a complex one. Even though the content of individual substances in water may not exceed the permissible upper limit, yet this does not mean that the water can be classified as being in excellent condition or that it can be used for drinking and domestic water supply. The water quality can also be compromised by the total adverse effects of various substances, which individually have concentrations below the permissible standard.

In the differentiated approach, the condition of groundwater is determined by individual physicochemical indicators. The disadvantage is that it does not give an overall assessment of the water status, while in a complex approach the status of groundwater is determined by multiple indicators, and the final result is presented in the form of a score, ranking or classification. Also, there must be a clear formulation of the rating scale, the application of weight and purpose of the method: indicative, comparative, for categorization, solving a specific scientific or applied problem, etc. The advantage of this approach is that it provides an overall assessment of the quality status of a water body.

The assessment of groundwater quality includes the following main steps: choice of method; selection of the parameters to be included in the assessment; setting the weight of the selected parameters; and classification of groundwater according to the calculated quality index. This article represents a comprehensive approach to assessing the qual-

ity of shallow groundwater on the territory of Bulgaria by determining the groundwater quality index (GWQI). In essence, the method for assessing water quality is a weighted arithmetic method, which aims to assess the overall water quality in relation to a number of selected parameters.

The methodology for determining the quality index is described by equations (1) to (5). The evaluation of the quality index is performed according to the equation (1) (Yogendra and Puttaiah, 2008; Jareda, *et al.*, 2016):

$$GWQI = \frac{\sum_{i=1}^n W_i \times Q_i}{\sum_{i=1}^n W_i}, \quad (1)$$

where W_i is the unit weight of each parameter; Q_i is a measure of the quality of each parameter; and n is the number of parameters.

The quality rating (Q_i) has been calculated, using the determined average value (M_i) and the permissible maximum value of the parameters (S_i) for the quality of drinking water defined in the national legislation (Regulation No. 9, 2001). The quality rating (Q_i) for each parameter has been calculated, using the equation (2):

$$Q_i = 100 \times \frac{|M_i - I_i|}{S_i - I_i}, \quad (2)$$

where M_i is the observed average value of the i^{th} parameter; I_i is the ideal value in the i^{th} parameter. The value of zero has been assumed for I_i , except for the parameters of pH ($I = 7.0$) and dissolved oxygen (D.O., $I = 14.6$ mg/l) (Yogendra and Puttaiah, 2008; Jareda *et al.*, 2016). S_i is the standard value of the i^{th} parameter. In the present study, for the indicators bicarbonate and TDS for the upper limit, the values given in the document of the World Health Organization Guidelines for Drinking-Water Quality (WHO, 2011) were used, as the maximum allowable value for them is missing in Regulation No. 9 (2001).

The unit weight (W_i) of each parameter is inversely proportional to the value of the standard parameter, and it is calculated, using the equation (3) (Mohan *et al.*, 1996) or (4) (Jareda *et al.*, 2016):

$$W_i = \frac{1}{S_i} \quad (3)$$

$$W_i = \frac{K}{S_i}, \quad (4)$$

where K is a proportional constant, which is calculated by the equation (5):

$$K = \frac{1}{\sum_{i=1}^n \left(\frac{1}{S_i} \right)} \quad (5).$$

Having calculated the GWQI values, the ground waters of Bulgaria were classified into several classes by type and according to their quality. In order to determine the status of groundwater, two classifications with the corresponding five intervals (Brown *et al.*, 1972; Chatterjee and Raziuddin, 2007; Sahu and Sikdar, 2008), have been most commonly used. In this paper, the classification of Brown *et al.* (1972) and Chatterjee and Raziuddin (2007) was selected as most appropriate according to the calculated quality index (Table 2).

Table 2

Classification of groundwater quality based on WQI (GWQI) – drinking water quality rating

WQI*	WQI**	STATUS
0–25	<50	Excellent Water
26–50	50–100	Good Water
51–75	100–200	Poor Water
76–100	200–300	Very Poor Water
>100	>300	Unfit for drinking

*Source: Brown *et al.* (1972), Chatterjee and Raziuddin (2007)

**Source: Sahu and Sikdar (2008)

RESULTS AND DISCUSSION

Types of groundwater

Piper diagram and Kurlov equation

In this study, the types of shallow ground waters on the territory of Bulgaria are classified according to Piper and Kurlov. With regard to cations, waters are mainly rich in calcium ions, with the exception of hard waters, which by cationic composition appear without a dominant type (Fig. 11). With regard to anions, all waters can be described as hydrocarbonate. Hence, the dominant type of groundwater is Ca-HCO₃.

According to Kurlov equation, waters from the hypergenic zone of Bulgaria are hydrocarbonate-calcium-magnesium, with the exception of hard waters, which are hydrocarbonate-magnesium-calcium (Fig. 12). Very soft waters are bicarbonate-calcium-magnesium-sodium. Soft waters, moderately hard waters, and rather hard waters are bicarbonate-calcium-magnesium, and hard waters are bicarbonate-magnesium-calcium.

Fig. 11. The Piper diagram of groundwater chemistry in the study area.

Water types	Kurlov equation
very soft	$\frac{\text{HCO}_3^- 74.675 \text{ SO}_4^{2-} 15.558 \text{ Cl}^- 9.767}{\text{Ca}^{2+} 49.912 \text{ Mg}^{2+} 26.120 \text{ Na}^+ 23.967}$
soft	$\frac{\text{HCO}_3^- 79.509 \text{ SO}_4^{2-} 11.755 \text{ Cl}^- 8.736}{\text{Ca}^{2+} 63.116 \text{ Mg}^{2+} 23.180}$
moderately hard	$\frac{\text{HCO}_3^- 86.830 \text{ SO}_4^{2-} 6.666 \text{ Cl}^- 6.504}{\text{Ca}^{2+} 61.113 \text{ Mg}^{2+} 24.613}$
rather hard	$\frac{\text{HCO}_3^- 89.031 \text{ Cl}^- 6.590}{\text{Ca}^{2+} 61.283 \text{ Mg}^{2+} 26.283}$
hard	$\frac{\text{HCO}_3^- 74.772 \text{ SO}_4^{2-} 10.725 \text{ Cl}^- 14.503}{\text{Mg}^{2+} 46.268 \text{ Ca}^{2+} 37.847}$

Fig. 12. The diagram of groundwater chemistry according to Kurlov equation.

Chadha diagram

Groundwater from the hypergenic zone is expected to fall into field 5 of the Chadha Diagram, where the water type is Ca-Mg-HCO₃ (Fig. 13). In this field, the five weak acidic anions (HCO₃²⁻ and CO₃²⁻) exceed the strong acidic anions (Cl⁻ and SO₄²⁻). In addition, the alkaline earth metals (Ca²⁺ and Mg²⁺) exceed the salt alkalis (Na⁺ and K⁺).

Groundwater quality index (GWQI or WQI) – results

The groundwater quality index for the shallow groundwater was calculated, making use of the spa-

Fig. 13. Chadha diagram showing the groundwater type and the geochemical processes.

tially distributed mean values of the concentration of the individual major ions in the groundwater of Bulgaria according to Kehajov (1968). To determine the quality of groundwater, equation (1) and equation (4) were used to calculate the weight of the individual parameters at a constant $K = 7.947$

(Table 3). Using equation (3) in order to determine the weight of the individual parameters, the calculations for GWQI are listed in Table 4.

The groundwater quality index varies from 13 to 92 (Fig. 14). These values indicate that the water can be used for drinking purposes, *i.e.*, there is no excess of the critical value of 100, above which the water is deemed unsuitable for drinking. Using the classifications of Brown *et al.* (1972) and Chatterjee and Raziuddin (2007), shallow groundwater on the territory of Bulgaria can be classified in the following manner: waters of excellent quality (3% of the studied area); waters of good quality (39%); waters of poor quality (22%); and waters of very poor quality 31% of the studied area (see Table 5). In Kehajov's (1968) paper, for about 5% of the groundwater in the hypergenic zone (corresponding to very hard water) no data was presented.

For the territory of Bulgaria, the groundwater quality index has the lowest values in the high mountainous regions (Table 5), where water exchange is most intensive. In these areas, the hypergenic zone is always well washed. This is an ultra-fresh water exchange zone – or these are areas with rapid chem-

Fig. 14. Spatial distribution of GWQI in the study area.

Table 3
Weights for determining the groundwater parameters, and its quality index for the study area

Constant K = 7.947							
Type	Parameters	Average value, mg/l	Regulation No9	Weight, $W_i=K/S_i$	Q_i	$W_i \times Q_i$	Status**
Very soft water	Na+K, mg/l	9.2	200	0.040	4.600	0.183	Excellent water
	Ca, mg/l	16.7	150	0.053	11.133	0.590	
	Mg, mg/l	5.3	80	0.099	6.625	0.658	
	Cl, mg/l	5.7	250	0.032	2.280	0.072	
	SO ₄ , mg/l	12.3	250	0.032	4.920	0.156	
	HCO ₃ , mg/l	75	120*	0.066	62.500	4.139	
	TH, meq/l	1.269	12	0.662	10.575	7.003	
	TDS, mg/l	124.2	500*	0.016	24.840	0.395	
Sum =				1.000		13	
GWQI = 13/1 = 13							
Soft water	Na+K, mg/l	14.8	200	0.040	7.400	0.294	Good water
	Ca, mg/l	44	150	0.053	29.333	1.554	
	Mg, mg/l	9.8	80	0.099	12.250	1.217	
	Cl, mg/l	11.3	250	0.032	4.520	0.144	
	SO ₄ , mg/l	20.6	250	0.032	8.240	0.262	
	HCO ₃ , mg/l	177	120*	0.066	147.500	9.768	
	TH, meq/l	3	12	0.662	25.000	16.556	
	TDS, mg/l	277.5	500*	0.016	55.500	0.882	
Sum =				1.000		31	
GWQI = 31/1 = 31							
Moderately hard water	Na+K, mg/l	17.2	200	0.040	8.600	0.342	Good water
	Ca, mg/l	64.3	150	0.053	42.867	2.271	
	Mg, mg/l	15.7	80	0.099	19.625	1.950	
	Cl, mg/l	12.1	250	0.032	4.840	0.154	
	SO ₄ , mg/l	16.8	250	0.032	6.720	0.214	
	HCO ₃ , mg/l	278	120*	0.066	231.667	15.342	
	TH, meq/l	4.5	12	0.662	37.500	24.834	
	TDS, mg/l	404.1	500*	0.016	80.820	1.285	
Sum =				1.000		46	
GWQI = 46/1 = 46							
Rather hard water	Na+K, mg/l	19.6	200	0.040	9.800	0.389	Poor water
	Ca, mg/l	84.2	150	0.053	56.133	2.974	
	Mg, mg/l	21.9	80	0.099	27.375	2.719	
	Cl, mg/l	16	250	0.032	6.400	0.203	
	SO ₄ , mg/l	14.4	250	0.032	5.760	0.183	
	HCO ₃ , mg/l	372	120*	0.066	310.000	20.530	
	TH, meq/l	6	12	0.662	50.000	33.113	
	TDS, mg/l	528.1	500*	0.016	105.620	1.679	
Sum =				1.000		62	
GWQI = 62/1 = 92							
Hard water	Na+K, mg/l	39.1	200	0.040	19.550	0.777	Very poor water
	Ca, mg/l	81.2	150	0.053	54.133	2.868	
	Mg, mg/l	60.2	80	0.099	75.250	7.475	
	Cl, mg/l	55	250	0.032	22.000	0.699	
	SO ₄ , mg/l	55.1	250	0.032	22.040	0.701	
	HCO ₃ , mg/l	488	120*	0.066	406.667	26.932	
	TH, meq/l	9	12	0.662	75.000	49.669	
	TDS, mg/l	778.6	500*	0.016	155.720	2.475	
Sum =				1.000		92	
GWQI = 92/1 = 92							

*Source: WHO (2011)

**Source: Brown *et al.* (1972), Chatterjee and Raziuddin (2007)

Table 4
Weighting used for determining the groundwater parameters, and its quality index for the study area

Type	Parameters	Average value, mg/l	Regulation No9	Weight, $W_i = 1/S_i$	Q_i	$W_i \times Q_i$	Status**
Very soft water	Na+K, mg/l	9.2	200	0.005	4.600	0.023	Excellent water
	Ca, mg/l	16.7	150	0.007	11.133	0.074	
	Mg, mg/l	5.3	80	0.013	6.625	0.083	
	Cl, mg/l	5.7	250	0.004	2.280	0.009	
	SO ₄ , mg/l	12.3	250	0.004	4.920	0.020	
	HCO ₃ , mg/l	75	120*	0.008	62.500	0.521	
	TH, meq/l	1.269	12	0.083	10.575	0.882	
	TDS, mg/l	124.2	500*	0.002	24.840	0.050	
			Sum =	0.126		1.661	
GWQI = 1.661/0.126 = 13							
Soft water	Na+K, mg/l	14.8	200	0.005	7.400	0.037	Good water
	Ca, mg/l	44	150	0.007	29.333	0.196	
	Mg, mg/l	9.8	80	0.013	12.250	0.153	
	Cl, mg/l	11.3	250	0.004	4.520	0.018	
	SO ₄ , mg/l	20.6	250	0.004	8.240	0.033	
	HCO ₃ , mg/l	177	120*	0.008	147.500	1.229	
	TH, meq/l	3	12	0.083	25.000	2.085	
	TDS, mg/l	277.5	500*	0.002	55.500	0.111	
			Sum =	0.126		3.862	
GWQI = 3.862/0.126 = 31							
Moderately hard water	Na+K, mg/l	17.2	200	0.005	8.600	0.043	Good water
	Ca, mg/l	64.3	150	0.007	42.867	0.286	
	Mg, mg/l	15.7	80	0.013	19.625	0.245	
	Cl, mg/l	12.1	250	0.004	4.840	0.019	
	SO ₄ , mg/l	16.8	250	0.004	6.720	0.027	
	HCO ₃ , mg/l	278	120*	0.008	231.667	1.931	
	TH, meq/l	4.5	12	0.083	37.500	3.125	
	TDS, mg/l	404.1	500*	0.002	80.820	0.162	
			Sum =	0.126		5.838	
GWQI = 5.838/0.126 = 46							
Rather hard water	Na+K, mg/l	19.6	200	0.005	9.800	0.049	Poor water
	Ca, mg/l	84.2	150	0.007	56.133	0.374	
	Mg, mg/l	21.9	80	0.013	27.375	0.342	
	Cl, mg/l	16	250	0.004	6.400	0.026	
	SO ₄ , mg/l	14.4	250	0.004	5.760	0.023	
	HCO ₃ , mg/l	372	120*	0.008	310.000	2.583	
	TH, meq/l	6	12	0.083	50.000	4.169	
	TDS, mg/l	528.1	500*	0.002	105.620	0.211	
			Sum =	0.126		7.778	
GWQI = 7.778/0.126 = 62							
Hard water	Na+K, mg/l	39.1	200	0.005	19.550	0.098	Very poor water
	Ca, mg/l	81.2	150	0.007	54.133	0.361	
	Mg, mg/l	60.2	80	0.013	75.250	0.941	
	Cl, mg/l	55	250	0.004	22.000	0.088	
	SO ₄ , mg/l	55.1	250	0.004	22.040	0.088	
	HCO ₃ , mg/l	488	120*	0.008	406.667	3.389	
	TH, meq/l	9	12	0.083	75.000	6.254	
	TDS, mg/l	778.6	500*	0.002	155.720	0.311	
			Sum =	0.126		11.530	
GWQI = 11.530/0.126 = 92							

*Source: WHO (2011)

**Source: Brown *et al.* (1972), Chatterjee and Raziuddin (2007)

Table 5
Overview of the results regarding GWQI

Water type	Average level*, m	Result	Status**	% of Bulgarian territory
Very soft water	1541	13	Excellent	3
Soft water	921	31	Good	24
Moderately hard water	499	46	Good	15
Rather hard water	293	62	Poor	22
Hard water	174	92	Very poor	31
Very hard water	119	No data	–	5

*Source: DEM 50 m

**Source: Brown *et al.* (1972), Chatterjee and Raziuddin (2007)

ical erosion (Kehajov, 1968). Conversely, the higher values of the groundwater quality index are in the lower hypsometric zone of the country (Fig. 15a, b), in the aeration zone of which large amounts of salts of alkali (Na^+ and K^+ ions) and alkaline earth metals have accumulated (Ca^{2+} and Mg^{2+} ions). These are mostly areas with slow chemical erosion (Kehajov, 1968).

The composition of groundwater is determined by the concentration of dissolved salts in the water itself. The composition depends on the characteristics of the rocks, with which the water has been, or is presently, in contact, as well as on the rock-water interaction, so the composition of the rock is very important for the quality of groundwater. The cations content in groundwater depends primarily on the mineral composition of the rock.

CONCLUSION

The construction of a method for assessing the groundwater quality depends on the quantity and

quality of the source information; the application of weighting or arranging according to certain criteria of the indicators used (classified as harmful, less harmful, primary, secondary); and the state of the existing regulatory framework. The geological setting, typical for the country should also be taken into consideration. A precise wording of the rating scale, and the number and type of physical-chemical parameters is also very important, *i.e.*, they might exert a greater or lesser effect on the quality of water. In this study, for the calculation of a groundwater quality index, only publicly available data about the macro ions has been used. It is advisable, however, to have other data included as well, such as information regarding the micro- and meso-ions.

The groundwater quality index varies in the range of 13 to 92, and should be below the critical value of 100, above which the water is considered unsuitable for drinking purposes. In conclusion, the shallow ground waters on the territory of Bulgaria can be classified in the range of being waters of excellent quality to waters of very poor quality.

Fig. 15. Dependence of GWQI versus the average altitude (a) and water status versus the average altitude above sea level (b).

The method for groundwater quality assessment shown here is a simple calculation model that provides an integrated and more thorough picture of groundwater quality. Determining the GWQI is one way of showing the state of groundwater as a cumulatively derived numerical expression, the resulting final number providing a certain status, or grouping the waters into certain quality classes. The index can be useful in assessing the condition of groundwater not only by specialists, but also by the Basin Directorates in assessing the overall quality of the groundwater body on the territory of Bulgaria.

The present study is based only upon publicly available information, and shows its applicability for regional hydro-chemical assessments. This methodology could also be used for up-to-date as-

sessments of the groundwater quality in Bulgaria and its changes in the course of time, when current data is supplied by interested institutions, such as the Ministry of Environment and Waters, and the Basin Directorates.

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