J. Elem. s. 845–852

DOI: 10.5601/jelem.2014.19.2.463

BORON CONCENTRATIONS IN GROUNDWATER INTENDED FOR CONSUMPTION FROM INTAKES LOCATED IN NORTHERN POLAND

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Abstract

The studies on boron concentrations were carried out on the samples collected from the groundwater intakes located in Northern Poland in the Lower Vistula Valley and in the Starogard Lakeland with diversified hydro-geological conditions and depths. The 57 samples of water for assays were collected from the following intakes: Tczew "Park" and Tczew "Motława", Gniew, Wielkie Walichnowy, Małe Walichnowy, and Pelplin. The deepest drillings extended to 180 m (cretaceous stages), out of which 20% comprised quaternary formations up to 123 m deep. The analysis of water samples in these regions was performed from 2009-2011. The geological architecture of these areas was identified based on the legal documentation on water utilization submitted by the operators of the water intakes. The Polish sanitary regulations specify that the maximum content of boron in drinking water is 1.0 mg dm^{-3}. That it was found in the waters mesoregion Starogard Lakeland may be assumed to be good in the context of chemical status, because in all of the 24 water samples tested, the boron concentration did not exceed the threshold value. In the Lower Vistula Valley mesoregion in 17 samples out of 33 tested, the level of boron exceeded 1.0 mg dm^{-3}, which means that prior to consumption these waters require treatment to reduce the concentration of this element to the permissible limits. Slightly higher concentrations of boron (on average 1.63 mg dm^{-3}) were detected in water deposited in the cretaceous formations situated in Wielkie Wachlinowy and Małe Wachlinowy. It was also found that the content of boron in groundwater depended on the nature of geological layers from which the tested water samples were collected. The statistical analysis demonstrates that the aquifer stages exerted a significant impact on the content of boron in the tested water samples and the differences between them are significant.

Key words: boron, groundwater, aquifer stages, water quality assessment.

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STĘŻENIE BORU W WODACH PODZIEMNYCH POBIERANYCH DO SPOŻYCIA Z UJĘĆ W PÓLNOCNEJ POLSCE

Abstrakt

Badania stężenia boru w wodach podziemnych pobieranych z ujęć położonych w północnej Polsce prowadzono w regionach Doliny Dolnej Wisły i Pojezierza Starogardzkiego, charakteryzujących się zróżnicowanymi warunkami hydrogeologicznymi i głębokością ich zalegania. Próbki wody do analiz pobierano z ujęcia Tczew ,,Park" i Tczew ,,Motława", Gniew, Wielkie Walichnowy, Małe Walichnowy i Pelplin. Najgłębsze wiercenia na tym obszarze osiągnęły głębokość 180 m (piętra kredy), z czego 20% obejmowały formacje czwartorzędowe o głębokości do 123 m. Analizę 57 próbek wody z ww. regionów przeprowadzono w latach 2009-2011. Budowę geologiczną badanych regionów rozpoznano na podstawie operatów wodnoprawnych udostępnionych przez eksploatatorów ujęć. Maksymalną zawartość boru w wodach pitnych polskie przepisy sanitarne określają na 1,0 mg dm^{-3}. Wykazano, że wody mezoregionu Pojezierza Starogardzkiego można uznać za dobre pod względem stanu chemicznego, ponieważ we wszystkich 24 badanych próbkach wody zawartość boru nie przekroczyła wartości granicznej. W mezoregionie Doliny Dolnej Wisły aż w 17 próbkach, na zbadane 33, poziom boru przekroczył 1,0 mg dm^{-3}, co oznacza, że wody te przed przeznaczeniem do konsumpcji wymagają uzdatniania do poziomu dopuszczalnej jego zawartości. Nieco większą zawartość boru (średnio 1,63 mg dm^{-3}) stwierdzono w wodach utworów kredy w miejscowościach Wielkie Walichnowy i Małe Walichnowy. Stwierdzono również, że zawartość boru w wodach podziemnych była zależna od rodzaju pokładów geologicznych, z których pochodziła badana woda. Analiza statystyczna potwierdziła, że piętra wodonośne miały duży wpływ na zawartość boru w badanych wodach, a różnice między nimi należy uznać za istotne.

Słowa kluczowe: bor, piętro wodonośne, wody gruntowe, ocena jakości wody.

INTRODUCTION

Water is one of the most important components of the environment in which the organisms live. Therefore, pollution of the aquatic environment causes a variety of major changes that are generally unfavourable to humans. Hence, it is important to constantly monitor water quality in order to undertake timely preventive and remedial measures (Koc et al. 2006, Koc et al. 2007, Czekała et al. 2011, Wons et al. 2012, Papciak et al. 2013).

In nature, boron is found mainly as borosilicates and tourmalines in sediment rocks. In many lakes it is present as borax and in some natural water sources as boric acid. Boron compounds are transferred into water with industrial liquid wastes and communal sewage (Woods 1994). According to Kabata-Pendias and Pendias (1999), anthropogenic emission of boron into the environment may also originate from coal combustion, the chemical industry and rocket fuels. The concentration of boron in drinking water does not usually exceed 1 mg dm^{-3}, but also higher concentrations are detected in water from natural sources. The concentration of boron in groundwater ranges from below 0.3 mg dm^{-3} to over 100 mg dm^{-3}. The average content of boron in groundwater in Italy and Spain is 0.5-1.5 mg dm^{-3}, and in the Netherlands and United Kingdom it amounts to 0.6 mg dm^{-3}. Approximately 90% of water samples collected in Denmark, France and Germany contained boron in concentrations below 0.3 to 0.1 mg dm^{-3} (WHO 1998, Haberer 1996). In Turkey, in areas where borax mining is concentrated, the content of boron in water ranged from 2.0 to 29.0 mg dm^{-3} (Cöl, Cöl 2003). In Eastern Europe, high concentrations of boron were detected in some highly mineralized natural waters in Romania (20 mg dm^{-3}), Georgia (to 10 mg dm^{-3}), Slovakia (up to 9.48 mg dm^{-3}) and Slovenia (5.5 mg dm^{-3}). In hydrogeochemical conditions typical of groundwater in Poland, the boron concentration ranges from 0.01 to 0.5 mg dm^{-3} (WHO 2009). Local concentrations of boron in water may be associated with both an elevated content in surrounding geological formations and the presence of other contaminations such as fluorides (Koc et al. 2006, Queste et al. 2001).

Boron is a micro-component, which together with calcium is involved in the process of bone formation and prevents caries. Apart from its natural metabolic functions, it has been shown that it induces multiple pathological changes. It has been found that boron intoxication in humans causes convulsions, anaemia, vomiting, diarrhoea and skin inflammation. The organs that are exposed to immediate damage include the central nervous system, gastrointestinal tract, skin and mucous membranes, liver, and kidneys (Culvar, Hubbard 1996). The permissible limits of boron concentration in water have been thus specified and the national standards for drinking water quality are based on the guidelines by the World Health Organization (WHO 1998) and requirements set in the EU and Polish regulation 98/83/EC (*EU Council Directive* ... 1998, WHO 1998, *Regulation* … 2007).

MATERIALS AND METHODS

The studies on boron concentrations were carried out on the samples collected from the groundwater intakes located in Northern Poland in the Lower Vistula Valley and on Starogard Lakeland with diversified hydro-geological conditions (Koc et al. 2010). The deepest drillings extended to 180 m (cretaceous stages), out of which 20% comprised quaternary formations up to 123 m deep. The analysis of 57 water samples in these regions was performed from 2009-2011. The geological architecture of these areas was identified based on the legal documentation on water utilization submitted by the operators of the water intakes. Boron in water was determined with the methods specified in the Polish standards (POLISH STANDARD 2006). The samples of water for assays were collected from the following intakes: Tczew "Park" and Tczew "Motława", Gniew, Wielkie Walichnowy, Małe Walichnowy, and Pelplin. The data assembly was characterized with descriptive statistics. Environmental and technological data were used to calculate correlative relations and a one -way analysis of variance (Anova) with Duncan's test at $p \leq 0.05$. Mathematical and statistical processing of the results was performed with the package of statistical procedures included in Statistica 7.1 software (StatSoft).

RESULTS AND DISCUSSION

Boron concentration in water is determined by multiple factors. Hydro-geological conditions, i.e. depth of location, are important in the case of groundwater because they are associated with types of rocks with variable boron contents. In this context, it should be emphasized that strong correlations exist between the content of fluorite and boron (Queste et al. 2001). The present studies included hydro-geological conditions and depth of water location, which was described in detail in another publication (Wons et al. 2012). The statistical analysis demonstrates that the aquifer stages exerted a significant impact on the content of boron in the tested water samples (Table 1, Figure 1) and the differences between them are significant. The highest amounts of boron (ranging from 0.90 to 1.63 mg dm^{-3}, on average 1.28±0.20 mg dm^{-3}) were detected in the cretaceous aquifer stage (K). They were significantly higher than the content B in water in the tertiary stage – T (on average 0.89±0.07 mg dm^{-3}) and the quaternary stage – Q (0.24±0.06 mg dm^{-3}).

Such significance was also demonstrated for the tertiary and quaternary (TQ) water stages that were predominant on the intake Tczew "Motława" (0.41±0.08 mg dm^{-3}) as well as for the cretaceous-tertiary-quaternary stages (KTQ) on the intake Tczew "Park" (0.44±0.08 mg dm^{-3}). The diversification of boron content in water from the last two stages (TQ and KTQ) was statistically insignificant, which indicates a similarity of water properties on these intakes.

The analysis of geological cross-sections of the wells on both intakes (Koc et al. 2006, 2007, Wons et al. 2012) indicates a substantial similarity of geological formation located there. In general, waters of the Starogard Lakeland mesoregion that encompasses the intakes Tczew "Motława, Tczew "Park" and Pelplin, had a lower concentration of boron (Table 1) at 0.36±0.11mg dm^{-3} in

Table 1

Statistical description of boron concentrations (mg B dm^{-3}) in groundwater in 2009-2011

Region	Place	Place				Region		
		aquifer stages	*n*	average	SD	range	average	SD
Lower Vistula Valley	Małe Walichnowy	K	8	1.28	±0.20	0.90 - 1.63	1.17	±0.25
	Wielkie Walichnowy	K	16	1.28				
	Gniew	T	9	0.89	±0.07	0.79 - 0.99		
Starogard Lakeland	Tczew Motława	TQ	9	0.41	±0.08	0.31 - 0.53	0.36	±0.11
	Tczew Park	KTQ	7	0.44	±0.08	0.32 - 0.55		
	Pelplin	Q	8	0.24	±0.06	0.17 - 0.36		

SD – Standard Deviation

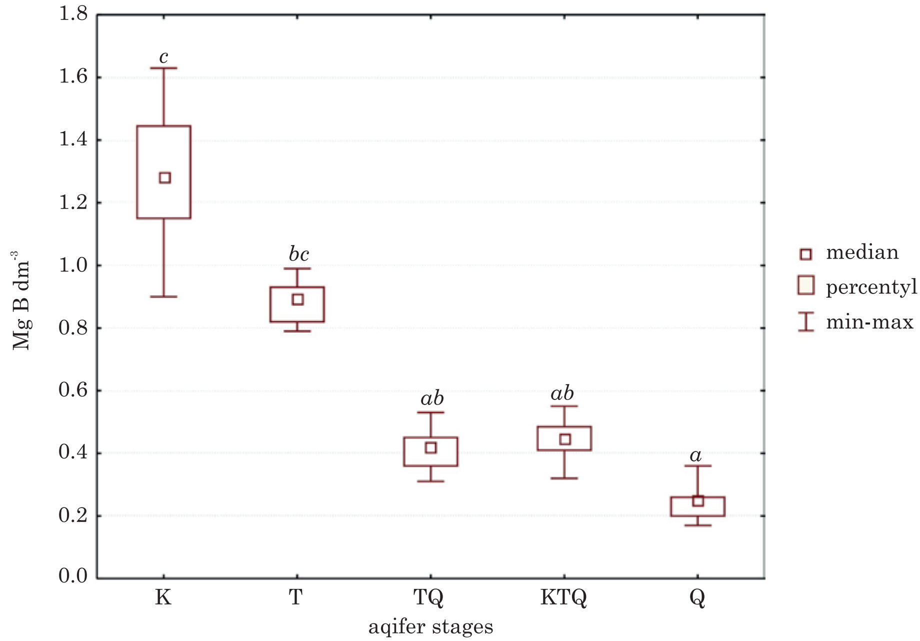

Fig. 1. Homogenous groups of boron content in groundwater and the margin mean values depending on the aquifer stages

comparison with 1.17±0.25 mg dm^{-3} in waters in the Lower Vistula Valley mesoregion.

Differences in boron content were also found between the investigated monitoring stations (Figure 2). Highly significant differences were found mainly between the locations in the individual mesoregions. This data confirms a previously formulated thesis on higher boron content in water from the stations in Małe Walichnowy and Wielkie Walichnowy and Gniew situated in the Lower Vistula Valley mesoregion. The average content of boron on the monitoring stations in both mesoregions was entirely different since the differences in boron content found between them were statistically insignificant.

Considering the value ranges and nearly four times higher average abundance of groundwater in boron from the intakes situated in the Lower Vistula Valley mesoregion, it is assumed that these differences result from a geological dissimilarity which influences the geochemical nature of drainage basin. It is associated with the presence of borates in both soil and in rocks; when they are released, mainly as borates from these formations, they may migrate to water layers. Moreover, a process of mixing of water from different aquifer layers cannot be excluded. In addition, it is possible that geochemical processes occur in groundwater layers and they may elevate or decrease the content of different elements and thus change the quality of groundwater (Barth 1988, Edmunds et al. 2003). It is important in the case of boron, as waters that are abundant in this element may pose a risk when

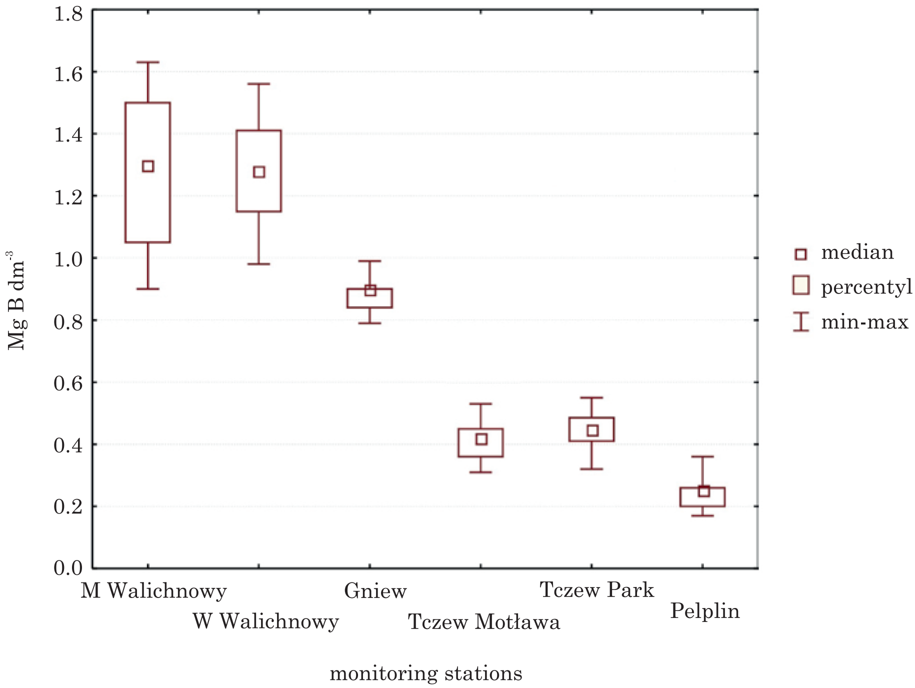

Fig. 2. Homogenous groups of boron content in groundwater and the margin mean values depending on the monitoring stations

drunk or used to irrigate fields or plants (VOUSTA et al. 2009). In addition, the authors emphasize the narrow range of concentrations between a deficiency in boron and the toxicity of this element.

Taking into consideration the criterion of boron content (1.0 mg dm^{-3}) for an evaluation of the quality of groundwater, it was found that waters in the mesoregion Starogard Lakeland may be assumed to be good in the context of chemical status (*Regulation* ... 2007, YAZBECK et al. 2005). This results from the fact that in all tested water samples, its concentration did not exceed the threshold value. The results were unlike for waters in the Lower Vistula Valley mesoregion. In 17 samples (app. 51%), out of 33 tested, the level of boron exceeded 1.0 mg dm^{-3}, which means that prior to consumption these waters require treatment to reduce the concentration of this element to the permissible limits.

CONCLUSIONS

1. The concentration of boron in groundwater extracted for consumption on Starogard Lakeland and in the Lower Vistula Valley was diversified depending on the exploited aquifer layers.

2. That it was found in the waters mesoregion Starogard Lakeland may be assumed to be good in the context of chemical status, because in all water samples tested, the boron concentration did not exceed the threshold value.

3. It was shown that a substantial proportion of water samples taken in the Lower Vistula Valley mesoregion (app. 52%) exceeded the lowest permissible concentration for boron set at 1.0 mg dm^{-3}.

4. A high concentration of boron was detected in the water samples collected in Wielkie Walichnowy and Małe Walichnowy and the quantitative range of concentrations ranged from 0.90 to 1.63 mg dm^{-3}.

5. The highest content of boron was measured in water extracted from the cretaceous stages and it thus requires treatment prior to consumption.

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