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ORIGINAL PAPER

Differences in health status of Slovak municipalities supplied with drinking water of different hardness values

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Abstract This epidemiological study of ecological type deals with the analysis of relationship between drinking water hardness and health status of inhabitants of the Slovak Republic. This relationship was investigated in two groups of more than 50,000 inhabitants living in 53 different municipalities. The first group was supplied with drinking water with low hardness, and the second group was supplied with drinking water with increased hardness. The health status of the population of both groups was monitored by means of health indicators, which represented 15-year average values, for 1994–2008. We investigated four major causes of death, namely cardiovascular, oncological, gastrointestinal and respiratory tract mortality, and evaluated the average life expectancy. The health status of inhabitants supplied with drinking water with increased hardness was significantly better than the health status of people supplied with drinking water with low hardness. For example, the relative mortality for cardiovascular diseases, oncological diseases, digestive tract diseases and respiratory diseases was 56%, 62%, 128% and 121% higher in the population supplied with soft drinking water compared to the population supplied with hard water, respectively. In addition, life expectancy was more than 4.5 years higher in the population supplied with hard drinking water. Our observation confirms the findings of previous studies on relationship between the water hardness and human health.

Keywords Drinking water · Hardness · Cardiovascular diseases · Oncological diseases · Gastrointestinal diseases · Respiratory diseases

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Introduction

The relationship between the hardness of drinking water and the incidence/mortality of cardiovascular disease has been described over 60 years ago (Kobayashi 1957). Over the past decades, this relationship has been confirmed with numerous works in the world literature (e.g. Catling et al. 2005, 2008; Rubenowitz–Lundin and Hiscock 2005; Jiang et al.

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2016; Gianfredi et al. 2017; Rapant et al. 2017). In the last 20 years, several papers have been published describing the impact of low-hardness drinking water on cancer (e.g. Yang et al. 1998, 2000; Ahn et al. 2007; Butler et al. 2010). There are also numerous studies describing the beneficial effects of calcium and magnesium in water on the incidence/mortality of diabetes mellitus or metabolic syndrome (Joslyn et al. 1990; Yang et al. 1999; Naumann et al. 2017), neurological disturbances, amyotrophic lateral sclerosis, preeclampsia in pregnant women, high blood pressure (reviewed by Rosborg 2020), bone fractures and bone development in children (Verd et al. 1992; Dahl et al. 2013; Huang et al. 2018, 2019), but these effects still need to be confirmed by more extensive research. The more epidemiological studies from around the world confirm this relationship, the more convincing evidence of the relationship between water hardness and health will exist and the better it will be possible to quantify this relationship.

In the Slovak Republic, the issue of the impact of different water hardness on the health of the population was mainly addressed by Rapant et al. (2014, 2015, 2017). They evaluated the average chemical composition of groundwater/drinking water in approximately all of the 2900 municipalities of the Slovak Republic and compared it to the health status of the inhabitants of the Slovak Republic. They found that municipalities, which have groundwater/drinking water with low hardness, i.e. low calcium (Ca) and magnesium (Mg) contents, are characterized by increased mortality, especially from cardiovascular diseases (CVD), oncological diseases (OD), respiratory diseases (RS) and diseases of the digestive system (DS). They may have committed certain inaccuracies because it was not always drinking water that people drink in individual municipalities, but the average composition of groundwater of individual municipalities compiled from the national geochemical database of groundwater in the Slovak Republic. However, 90% of the total volume of drinking water in Slovakia is derived from groundwater (Klinda and Lieskovská 2010), usually from local sources. In the present article, we deal with the direct evaluation of the impact of drinking water of different hardness values on the health status of the population. Thus, we assess the health status of the population that consumes drinking water of a precisely defined chemical composition from water sources of mass supply. Influence of different water hardness on the health status of inhabitants of the Slovak Republic was monitored in two groups of inhabitants, each supplied with drinking water of different hardness values. We evaluated the health status of the population on the basis of health indicators, which represented 15-year average values. We evaluated four main causes of death in Slovakia: mortality from cardiovascular diseases, oncological diseases, digestive tract diseases and respiratory diseases. These four diagnoses represent approximately 88% of the causes of death from all deaths in the Slovak Republic, namely CVD approximately 50%, OD approximately 25%, RS approximately 8% and DS approximately 6% (NHIC 2013). We also observed differences in life expectancy (lifetime expectancy at birth—LE) in both groups. The aim of the present epidemiological study is to find out whether there are significant differences in the health status of people supplied with drinking water of different hardness values in Slovakia. Water hardness represents the dissolved contents of Ca and Mg in water.

Materials and methods

Selection of municipalities

In order to monitor the expected impact of different water hardness on the health status of the population, we compiled two groups of municipalities within the Life Water and Health project (http://ns.uniba.sk/lifewaterhealth/), which are supplied with drinking water of different hardness values, thus with different contents of Ca and Mg. First, we divided the territory of the Slovak Republic according to the geological structure. Groundwater/drinking water with low hardness occurs mainly in silicate rock environments (granitoids, crystalline shales and volcanic rocks). Groundwater with increased hardness occurs mainly in carbonatic and flysch sedimentary rocks. Chemical analyses of drinking water were not available from all municipalities. In the territory of the Slovak Republic, approximately 10% of the municipalities do not have mass supply with drinking water. Also, many municipalities (especially larger ones) were supplied with drinking water from several sources and, thus, with different hardness values. In many municipalities, the mass supply of drinking water was only partial; some households used their own home wells to supply drinking water. All these municipalities, where the quality of drinking water was not clearly defined, were excluded from the selection. From the rest of the municipalities, we randomly selected municipalities supplied with drinking water of different hardness values. The first group of municipalities was administered with water of low hardness and the second group with water of high hardness (Fig. 1).

Each group included more than 50,000 inhabitants. The first group of municipalities, hereafter referred to as "soft" water, consisted of 34 municipalities supplied with drinking water with low Ca content of approximately ≤ 30 mg l^{-1}, Mg of approximately ≤ 10 mg l^{-1} and total water hardness of ≤ 1 mmol l^{-1}. The total population in this group was 52,676. The second group of municipalities, hereafter referred to as "hard" water, consisted of 21 municipalities with high Ca content of approximately ≥ 50 mg l^{-1}, Mg of approximately ≥ 25 mg l^{-1} and total water hardness of ≥ 2.5 mmol l^{-1}. The total population in this group was 53,118. During the 15 evaluated years, there was no change in the source of drinking water in any municipality. We selected municipalities with a minimum of 500 inhabitants. The numbers of inhabitants in municipalities were not random. It is clear from previous works (e.g. Rapant et al. 2010; Cvečková et al. 2016) that small municipalities with < 100 inhabitants often show unbalanced health indicators (small number error). We also wanted to avoid the fact that if we selected 4–5 municipalities with 10,000 inhabitants or more, we would not be able to obtain the necessary variability of health indicators. Inhabitants of municipalities with a total population of 500–5000 showed the most balanced health indicators and are most closely connected with the environment (Rapant et al. 2010; Cvečková et al. 2016). These are almost exclusively municipalities of rural character with approximately the same socio-economic characteristics. In the case of group of municipalities "soft" water, we have to select more municipalities due to the fact that drinking water originates from the silicate rocks of low water yield. Municipalities with several thousand inhabitants were rarely supplied with soft drinking water in Slovakia. An overview of the earmarked municipalities, the basic chemical composition of individual water sources, the number of inhabitants in individual municipalities, etc., is available on the website http://fns.uniba.sk/lifewaterhealth.

Compilation of the health indicators

Characteristics of health status of inhabitants of the two separate groups of municipalities are given on the basis of the so-called health indicators. Health

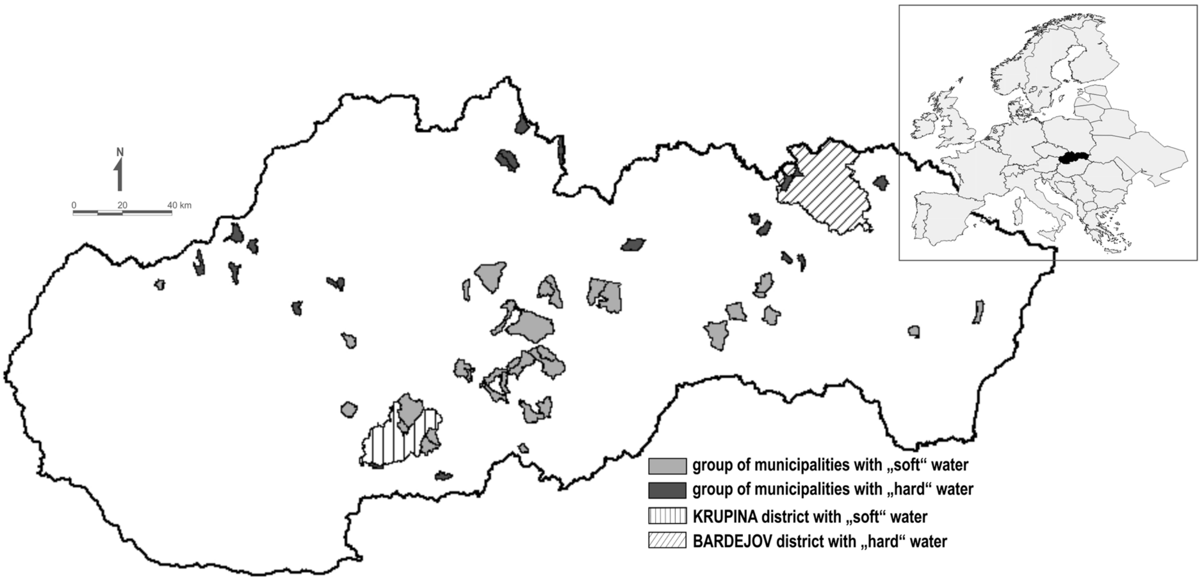

Fig. 1 Schematic map showing the location of the Slovak Republic in Europe and municipalities divided into the two groups: group of municipalities with "soft" water and group of municipalities with "hard" water

indicators (HIs) are indicators of the demographic growth and health of inhabitants and reflect the health status of the population (Last 2001). Data from the Statistical Office of the Slovak Republic for the period 1994–2008 were used (www.statistics.sk). Thus, all data represent 15-year averages. All health indicators were compiled on the basis of the International Classification of Diseases (ICD), 10th revision (www.who.int/classifications/icd/en/), in accordance with the WHO recommendation (e.g. Beaglehole et al. 1993; Jenicek 1995; Last 2001). All used HIs are robust, stable, easy to construct and internationally comparable. Each HI was compiled according to genders (men, women) and the whole population. We also approached the age differentiation of each HI. Totally, 96 HIs were compiled, of which 13 most important indicators are listed in Table 2. A complete description of all 96 HIs is available on the website http://fns.uniba.sk/lifewaterhealth. Mortality from all 2037 individual diagnoses listed in the ICD, 10th revision, was also processed for both groups of municipalities. The method of HI construction and the methodology of its calculations are described in detail in Rapant et al. (2014) and www.geology.sk/geohealth. All health indicators in both groups of municipalities were compared to each other and to the average value for the Slovak Republic. Municipalities with less than 100 inhabitants were not included in the Slovak average due to small number error. Overall, the Slovak average represents the average of 2762 municipalities (5.39 million inhabitants) and represents 99.87% of the population of the Slovak Republic. The group of municipalities "soft" water included 52,676 inhabitants, and the group of municipalities "hard" water included 53,118 inhabitants. The hard water group of municipalities thus represented 1.03-fold of the population in the "soft" water group.

Statistical analysis

In order to evaluate the statistical dependence between health indicators in municipalities supplied with drinking water of different hardness values, a two-sample Kolmogorov–Smirnov test was used. The calculations were carried out using the STATGRAPHICS program. The significance was determined based on the p values. In the case of $p < 0.001$, we consider the results very highly statistically significant, when $p < 0.01$—highly statistically proven— and when $p < 0.05$— we consider the results statistically significant.

Results

An overview of the average content of Ca, Mg and hardness of drinking water for both allocated groups of municipalities in comparison with the Slovak standard values for drinking water (Decree of the Ministry of Health of the Slovak Republic No. 247/2017 Coll.) is given in Table 1. Pursuant to the Slovak standard for drinking water, the water hardness is reported as (Ca + Mg) content in mmol l^{-1} and we use this modern unit also in this paper.

The basic characteristics of HIs are given in Table 2 and of the health status of the inhabitants in both selected groups of municipalities are shown in Table 3 compared to the national average values. Table 4 gives a detailed characteristic of all the evaluated main 13 HIs for both selected water groups, also compared to the national average values. It is clear from Tables 2, 3 and 4 that the group of municipalities supplied with soft drinking water has the values of all indicators significantly more unfavourable than the group of municipalities supplied with hard drinking water. Graphically, this fact is shown in Fig. 2.

The results of testing the statistical significance of health indicators of both groups of municipalities supplied with drinking water of different hardness values are shown in Table 5. In the case of premature death (PD) indicator, a statistically significant dependence was confirmed ($p = 0.013$). For all other HIs, very high statistical difference was found ($p < 0.001$).

Discussion

Drinking water, which is used in the Slovak Republic, must be regularly inspected at least twice a year in accordance with the Slovak standard for drinking water (Decree of the Ministry of Health of the Slovak Republic No. 247/2017 Coll.), depending on the size of the source. It is not possible to assume an increased content of any harmful substances such as potentially toxic elements, organic pollutants, bacteriological contamination and natural radioactivity parameters. For example, the nitrate content is very similar in both groups of municipalities. The nitrate content is

Table 1 Average content of Ca, Mg and water hardness in evaluated groups of municipalities in comparison with limit values of the Slovak standard for drinking water

Parameter	Limit value[a]	"Soft" water	"Hard" water
Ca (mg l^{-1})	> 30	20.7	70.12
Mg (mg l^{-1})	> 10	6.05	26.4
(Ca + Mg) (mmol l^{-1})	1.1–5.0	0.77	2.84

[a]Recommended value of the Decree of the Ministry of Health of the Slovak Republic no. 247/2017 Coll

Table 2 Basic characteristics of used health indicators

	HI	Description of HI	Units	Note
1	LE	Lifetime expectancy at birth	Years	Basic cross section indicator
2	CM	Crude mortality	Coefficient	Basic orientation in mortality
3	ReC	Relative mortality for selected cause of death	Coefficient	Malignant neoplasms C00-C97
4	ReI			Diseases of the circulatory system I00-I99
5	ReJ			Diseases of respiratory system J00-J99
6	ReK			Diseases of the digestive system K00-K93
7	SMR	Indirect age-standardized mortality rate of inhabitants to the Slovak standard (19 age groups)	% against SR	All deaths without choice
8	SMRC			Malignant neoplasms C00-C97
9	SMRI			Diseases of the circulatory system I00-I99
10	SMRJ			Diseases of respiratory system J00-J99
11	SMRK			Diseases of the digestive system K00-K93
12	PD	Premature death	% from all death	Whatever the cause
13	PYLL	Potential years of lost life	Years	Whatever the cause

12.1 mg l^{-1} and 17.3 mg l^{-1} in the group of municipalities "soft" water and "hard" water, respectively. There are also no differences in the contents of potentially toxic elements, which are otherwise very low, reaching generally $\sim 10^{-3}$ mg l^{-1}. However, there are significant differences in the content of Ca and Mg as well as water hardness between the two groups of municipalities. As can be seen from Table 1, the content of Ca, Mg and water hardness is approximately four times higher in the group of municipalities "hard" water compared to the group of municipalities "soft" water.

As in the case of Ca and Mg contents in both groups of municipalities, fundamental differences in HIs between the two groups of municipalities are also confirmed. It is clear from the results given in Tables 3 and 4 that all health indicators in the group of municipalities "soft" water are significantly worse than in the group of municipalities "hard" water. For example, the life expectancy in the "soft" water group is 4.58 years lower than in the "hard" water group. In the case of four main causes of death assessed in the Slovak Republic, the situation is the same. The relative mortalities for CVD, OD, RS and DS were 56%, 62%, 121% and 128% higher in the population supplied with soft drinking water than in the population supplied with hard drinking water, respectively.

In all health indicators, the group of municipalities "soft" water is worse than the national average and the group of municipalities "hard" water is better than the national average. This is also evident in Fig. 2. When averaging all 13 assessed HIs, HIs in the group of municipalities "hard" water are on average 62% better than in the group of municipalities "soft" water. For all evaluated main HIs, very high significant differences ($p < 0.001$) were confirmed by statistical testing (Table 5), with the exception of the PD indicator, where statistically verified dependence was confirmed ($p < 0.05$).

Table 3 Basic characteristics of health status of inhabitants of both water groups

Data for 1994–2008 (SUM)	Slovak Republic	Municipalities "soft" water	Municipalities "hard" water
Number of municipalities in the group	2762	34	21
Number of person-years	80,799,554	804,450	776,959
Number of deaths	785,328	10,740	5796
Number of premature deaths	225,518	3167	1521
Number of PYLL	3,184,312	46,417	21,527
Number of cancer deaths	172,995	2099	1249
Number of deaths due to cardiovascular diseases	429,239	6125	3315
Number of deaths due to respiratory diseases	46,435	704	307
Number of deaths from digestive diseases	38,994	557	235

Table 4 Differences in health indicators of selected two groups of municipalities compared to the Slovak Republic (national average)

	HI	Description of HI	Slovak Republic (2762 municipalities)	"Hard" water (21 municipalities)	"Soft" water (34 municipalities)
1	LE	Life expectancy at birth	72.65	74.58	70.00
2	CM	Crude mortality	9.72	7.47	13.35
3	ReC	Relative mortality for selected cause of death	214.10	160.92	260.92
4	ReI		531.24	427.10	761.39
5	ReJ		57.47	39.55	87.51
6	ReK		48.26	30.28	69.24
7	SMR	Indirect age-standardized mortality rate of inhabitants to the Slovak standard (19 age groups)	100	87.82	114.49
8	SMRC		100	83.53	10.77
9	SMRI		100	95.55	116.58
10	SMRJ		100	80.85	120.75
11	SMRK		100	87.82	114.49
12	PD	Premature death	28.82	27.15	29.95
13	PYLL	Potential years of lost life	3941.00	2773.53	5770.03

Of all 2037 individual diagnoses listed in the International Classification of Diseases (ICD), 10th revision (www.who.int/classifications/icd/en/), in neither case, lower number of deaths for the "soft" water group compared to the "hard" water group was recorded. When we focused on the individual reasons of death, the highest difference in the causes of death was observed in case of diagnosis I21–acute myocardial infarction, 3.23 times higher in the group of municipalities "soft" water, diagnosis I25–chronic ischaemic heart disease, 2.17 times higher in the group of municipalities "soft" water, and diagnosis C34–bronchial and lung malignancy, 2.17 times higher in the "soft" water than in the "hard" water group of municipalities. As the highest and the most noticeable difference is the number of deaths from the diagnosis of G80–infantile cerebral palsy. In the case of the "hard" water group, only two cases were recorded over the 15 years reviewed, while up to 34 cases in the "soft" water group. Due to the fact that the cases did not form local or time clusters, it can be assumed that the higher mortality was not caused by any infectious epidemic, but due to other causes; we hypothesize different drinking water quality, namely Ca and Mg

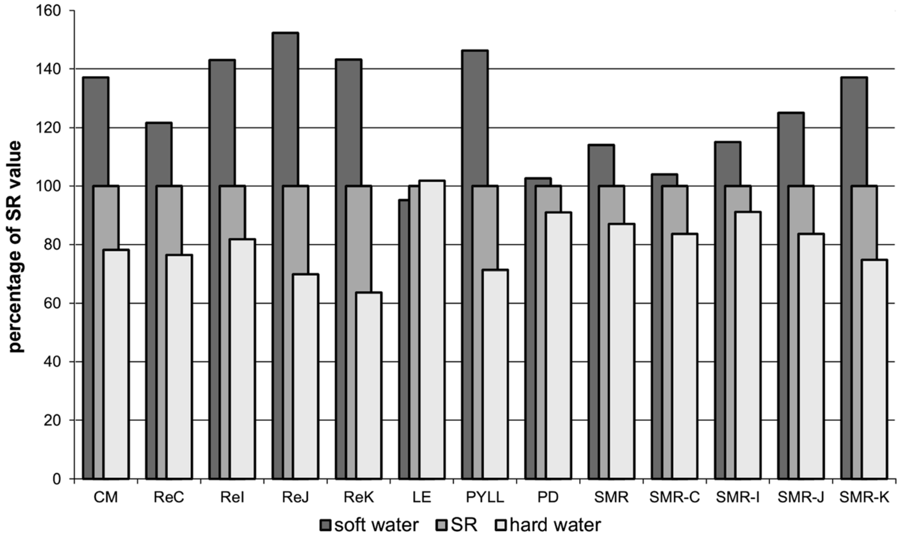

Fig. 2 Differences in health indicators of selected two groups of municipalities compared to the Slovak Republic (national average)

Table 5 Results of testing of statistical significance of HI differences between the two selected groups of municipalities

	HI	Description of HI	DN[a]	*p* value	Interpretation	
1	LE	Lifetime expectancy at birth	1	0	+++	Very highly statistically significant difference
2	CM	Crude mortality	0.970588	0.0000001	+++	
3	ReC	Relative mortality for selected cause of death	0.882353	0	+++	
4	ReI		0.882353	0	+++	
5	ReJ		0.705882	0.0000481	+++	
6	ReK		0.710084	0.0000004	+++	
7	SMR	Indirect age-standardized mortality rate of inhabitants to the Slovak standard (19 age groups)	0.922969	0	+++	
8	SMRC		0.610644	0.000124	+++	
9	SMRI		0.614846	0.000109	+++	
10	SMRJ		0.570028	0.000433	+++	
11	SMRK		0.578431	0.0003375	+++	
12	PD	Premature death	0.413165	0.0132	+	Statistically verified dependency
13	PYLL	Potential years of lost life	0.87535	0	+++	Very highly statistically significant difference

[a]DN—Test statistic for the two-sample Kolmogorov–Smirnov test, *p* value—approximate significance level, $p < 0.05$—verified dependence (+), $p < 0.01$—high dependence (++), $p < 0.001$—very high dependence (+++)

contents. Overall, the group of municipalities with “soft” water have all HIs relatively highly inhomogeneous, with many outlying or extreme values. The group of municipalities with “hard” water is similar in HIs, and there are no extraordinary extreme values in this group of municipalities. Fourteen municipalities out of 34 municipalities supplied with “soft” drinking water recorded extreme values of some HIs also within the whole territory of the Slovak Republic. This heterogeneity is caused by a significantly higher number of deaths and increased mortality of the population, which is manifested in almost all monitored HIs. No extreme values were documented in municipalities supplied with “hard” water. This finding is reported for the first time in epidemiological studies dealing with the water hardness and human health.

The health status of the population is also affected by many other factors, in addition to the content of Ca and Mg in drinking water. The main determinants of human health include lifestyle, genetic factors, the level and availability of health care, socio-economic factors, the quality of the environment and a number of other physical, chemical and biological factors. The Slovak Republic is a relatively small country with an area of $\sim$ 50,000 km^2 and a population of about 5.5 millions. All municipalities in both groups are relatively small (500 to 5000 inhabitants) and exclusively rural in nature. The quality of the environment in all municipalities is high, and there is no serious anthropogenic pollution. There are no large industrial enterprises in the evaluated municipalities that would pollute the air and other components of the environment. The population of the Slovak Republic is relatively very homogeneous. There is only a relatively large minority of the Roma population (approximately 5%) who lives mostly in segregated settlements, and their health is significantly worse than in the rest of the population. (They live on average 6–10 years less). The Central European population has a dominant representation. People from other continents and other races are only minimally represented (less than 1% of the total population). Several lifestyle surveys were carried out in the Slovak Republic (NHIC 2013; EHES 2016). These surveys were mainly focused on larger cities or districts and not carried out in municipalities investigated in this study. Therefore, the evaluation of the influence of all other health determinants on the health status of the population of the Slovak Republic is given on the example of two districts (also of a rural character), namely the district of Krupina and the district of Bardejov (Fig. 1). The district of Krupina is built by volcanic rocks, mainly andesites and their pyroclastics. As a result, groundwater, which is used to supply the population with drinking water, has low content of Ca and Mg. We also note that the district of Krupina is characterized by the worst health status of its inhabitants in the Slovak Republic. The district of Bardejov lies entirely on flysch carbonate rocks of the Paleogene, and the groundwater used to supply the population with drinking water has relatively high content of Ca and Mg. So the situation is similar to our case. The district of Krupina can be related to the group of municipalities "soft" water and the district of Bardejov to the group of municipalities "hard" water.

All available information on socio-economic parameters, level and availability of health care, lifestyle characteristics, environmental and health indicators of both districts is given in Table 6. It is clear from the data given in Table 6 that there are no significant differences between the two districts in the basic human health determinants. In most of the above health determinants, they are insignificantly worse in the district of Bardejov. Nevertheless, the health status of the district of Krupina, supplied with drinking water of lower Ca and Mg contents, is significantly worse than that of inhabitants living in the district of Bardejov, supplied with drinking water of higher Ca and Mg contents. Due to this fact and in accordance with world knowledge, we associate the worsened health status of the "soft" water group mainly with the deficient content of Ca and Mg.

Since this is an epidemiological study of the ecological type, it only works with the characteristics of the whole population, but does not check the known risk factors in individual persons. Of course, studies working with individuals provide a greater weight of evidence for the relationship being studied. However, this does not mean that the results of ecological studies should be questioned—simply because there is no reasonable explanation why the occurrence of important lifestyle factors such as nutrition or smoking should accurately copy natural (environmental) characteristics such as groundwater quality.

Calcium and magnesium are among the oldest recognized essential elements needed for human health (Prasad 1977). Their role in the human body is relatively well examined, although the complicated interrelationship with many other components of the body (and food) offers almost infinite scope for further research of these mechanisms. The content of both elements in drinking water and their impact on human health have been subjected to intensive research for 60 years, representing hundreds or thousands of published scientific papers, including hundreds of ones with primary epidemiological data.

Yet there is still much unclear. This stems primarily from two aspects:

- Both elements are not only taken with drinking water but mainly with food, and it is not possible to control the exact content in the diet of all individuals involved in epidemiological studies over long-term periods.

Table 6 List of selected socio-economic, health care and lifestyle characteristics and environmental and health indicators for Krupina and Bardejov districts compared with the Slovak Republic

Socio-economic characteristics[a]	Krupina	Bardejov	SR
Level of registered unemployment (% of population)	5.88	10.84	5.8
Average nominal monthly salary in Euro	694	614	957
Rate of gypsy nationality (% of population)	3	5	5
Health care characteristics[b]			
No. of physician posts per 10,000 population-adults (age 18 + years)	4.36	3.40	4.32
No. of physician posts per 10,000 population—children and adolescents (age 0–17 years)	6.86	7.44	9.87
Lifestyle characteristics[c,d]			
Regular physical activity in average (% of population)	45	39.5	58.5
Regular eating habits (% of population)	75	49	68
Smoking (% of population)	25	43	19.5
Excessive alcohol intake (% of population)	9.8	11	6.8
Health indicators			
LE	68.93	74.04	72.60
ReC00-C97	243.75	175.32	212.79
ReI00-I99	884.73	492.82	531.05
ReJ00-J99	81.32	26.62	58.08
ReK00-K93	76.04	25.39	45.83
Environmental indicators			
Ca [mg l^{-1}]	45.71	80.75	93.56
Mg [mg l^{-1}]	13.91	17.98	28.29
(Ca + Mg) [mmol l^{-1}]	1.73	2.75	3.5

[a]Statistical office of the Slovak Republic (www.statistics.sk, 2018)

[b]NHIC 2013

[c]Data source for Krupina district: www.geology.sk/lifeforkrupina

[d]Data source for Bardejov district and the Slovak Republic: EHES 2016—European Health Examination Survey (www.ehes.info), SR Slovak Republic

- Water contains not only calcium and magnesium but also a number of other minerals that may have a similar or opposite effect or may affect the absorption of both elements—again, checking all these factors in the studies is complicated and many older works completely omit this aspect. Many older works also did not examine the content of both elements in water individually, but only as their sum (water hardness).

The recommended daily dose of Ca for adults is between 700 and 1200 mg per day (Dietary Reference Intakes 2018) and the recommended daily dose of Mg is in a range of 320–420 mg per day (Magnesium. Office of Dietary Supplements 2018). Although dairy products are the most prominent source of Ca in the diet, drinking water is another important source. Water is a major component of the human body and involved in many body functions, including the transport of nutrients and the removal of waste products of metabolism and toxins. In order to maintain good hydration and body balance, daily intake should reach 1.2–2.5 litres of water, although needs may vary depending on age, physical activity, nutrition, health status or climatic conditions (Quattrini et al. 2016). Since the 1990s, studies have been carried out to assess the bioavailability of Ca contained in calcium-rich mineral water compared to its bioavailability in dairy products (Halpern et al. 1991; Van Dokkum et al. 1996; Wynckel et al. 1997; Bacciottini et al. 2001;

Brandolini et al. 2005; Greupner et al. 2017). These studies showed that Ca bioavailability from Ca-rich drinking water was equal to or even higher than its bioavailability from milk and dairy products. Most studies confirmed that Ca-rich drinking water had a positive effect on bone biomarkers and densitometric parameters (Costi et al. 1999; Meunier et al. 2005; Wynn et al. 2009a, b).

Daily Mg intake of 3.6 mg kg^{-1} is required to maintain physiological balance. In most of the developed countries, food intake of Mg is insufficient and ranges between 65 and 225 mg per day, depending on the geographic region. Several epidemiological studies in North America and Europe confirm that children and adults who consume Western-type diet are low in Mg (e.g. 30–50% recommended nutritional dose) (Altura et al. 2016). For example, at present 45% of US citizens are at risk of Mg deficiency and 60% of adults are under ADI (average dietary intake) (Costello et al. 2016; Food and Supplement Intake Data 2018; Workinger et al. 2018). Drinking water is an important source of Mg if it contains Mg at concentrations of about 30 mg l^{-1} (Swaminathan 2003).

The daily intake of Ca and Mg from drinking water is significantly different in the two groups of municipalities, supplied with drinking water of different hardness values. This difference amounts to 10–15% of the total daily required dose. Considering the intake of 2 litres of water per day, Ca and Mg intakes from water are approximately 40 mg day^{-1} and 12 mg day^{-1} in the group of municipalities "soft" water, respectively. This intake is more than 3–4-fold higher in the group of municipalities "hard" water, 120 mg day^{-1} for Ca and 52 mg day^{-1} for Mg. The fact that Ca and Mg are present in the form of free ions in drinking water should also be taken into account. Thus, they are more bioavailable than Ca and Mg in the diet where these essential elements are mostly bound in the form of complex organic compounds. Under insufficient intake of these elements by food and their borderline deficit, minor intake from drinking water might play a decisive health role.

The effect of low Mg content in drinking water on the increased incidence of CVD can now be considered as confirmed by several independent meta-analyses (Catling et al. 2008; Jiang et al. 2016; Gianfredi et al. 2017). The meta-analysis of Gianfredi et al. (2017) additionally found a statistically significant protective effect of water Ca on CVDs. In addition, decreased vascular flexibility and higher arterial age in people drinking soft water were confirmed (Rapant et al. 2019). It was also shown that people drinking Ca- and Mg-deficient water had a shorter lifespan (Rapant et al. 2017). If these associations from the intake of soft drinking water with the pathophysiology observed are valid, then also 10–15% of Ca and Mg from drinking water on a daily basis plays a very important role in human health.

Conclusion

Our HI data evaluated are quite extensive. They represent health data of more than 50,000 inhabitants in each group of municipalities supplied with drinking water of different hardness values over a period of 15 years. It is therefore approximately 1.6 million person-years. The achieved results confirmed a significantly worse health status of the population supplied with soft drinking water. In the case of cardiovascular and partially oncological diseases, a similar situation has been observed in many countries around the world. However, our results suggest that the deficiency of Ca and Mg in drinking water significantly contributes to increased mortality due to digestive tract and respiratory diseases, even more than due to cardiovascular and oncological diseases. This fact has not been already described in the world literature. Published data on increased digestive and respiratory system mortality associated with the hardness of drinking water are unknown. Only one older Russian study described the increased incidence of stomach and duodenal diseases associated with soft drinking water (Lutaj 1992). As with the four main causes of death in the Slovak Republic, diabetes mellitus was reported to be a cause of increased mortality in the soft water group. However, the statistical testing did not confirm a significant relationship between the two separate groups of water, and therefore, we did not include it in the study.

Deficient content of Ca and Mg in drinking water has, in general, a negative effect on human health. However, this deficit does not seem to affect all individuals equally. This is evidenced by a much higher incidence of extreme and outlying values of health indicators within the group of municipalities "soft" water.

Based on the results presented in this work as well as in numerous older studies, we believe that Ca and Mg contents in drinking water have a very significant impact on human health and should therefore be included in the WHO Guidelines for drinking water quality at least as a minimum recommended values or recommended range.

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