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Magnesium and calcium in drinking water in relation to cardiovascular mortality in Serbia

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A b s t r a c t.– The relationship between death from cardiovascular disease (CVD) and the levels of magnesium and calcium in drinking water was examined in 65 communities in Serbia. Waters were collected during the summer 1998 and analyzed for major cations and anions. Data for cardiovascular mortality were obtained from the study of Djordjević et al. (1998). The results obtained indicate a negative relationship between CVD mortality and the magnesium (Mg) level in drinking water. The hardness of water alone, with high calcium and low magnesium content shows a positive relationship with CVD mortality.

Key words: magnesium, calcium, sodium, drinking water, water hardness, cardiovascular mortality, Serbia.

INTRODUCTION

The chemical composition of natural waters is derived from many sources, including gases and aerosols from the atmosphere, weathering and erosion of rocks and soils, solution or precipitation reactions occurring below the land surface, and effects resulting from activities of man. However, the water hardness is primarily the result of interaction between water and geological formations containing it, or over which the water flows. The hardness of water is determined largely by its content of calcium (Ca) and magnesium (Mg) in solution. The major sources of Mg in ground and stream waters in Serbia are the highly magnesian ultramafic rocks (harzburgites, lherzolites and dunites) and serpentinites, which occupy vast regions, covering about 3000 km^2. The weathering process is active at the present time, but is restricted mostly to 5–6 cm below the surface of the rock. The course of this process is also evident by the presence of Mg–HCO_3 - type waters in all ultramafic massifs. Dolomites, $CaMg(CO_3)_2$, occur sporadically and are not an important source of Mg and Ca. Limestones of different age are abundant, providing Ca to the ground waters and streams. They cover vast regions, especially in Eastern Serbia. These two rock types, especially limestones, are mostly responsible for the hardness of the municipal waters in this country. Other sedimentary rocks, Paleozoic schists, crystalline schists, intrusive and effusive rocks of the granodioritic composition are also widespread, but are rather poor in magnesium and calcium.

The relatioship between water hardness and CVD mortality has been studied for more than 50 years. This connection was first described in Japan (Kobayashi, 1957), and subsequently a number of studies conducted in various countries have demostrated the relationship between CVD mortality and water hardness. A review on this subject was published by Chun-Yuh Yang et al. (1997).

In the todays world, the intake of dietary magnesium is often lower than the recommended dietary amounts (RDA): 6 mg/kg/day (Durlach, 1989). For example, the Gallup Ogranization has found that 72% of adult Americans are falling short of the RDA for Mg. For individuals at the borderline of Mg deficiency, Mg via drinking water can be an important contribution to the total intake (Yang et al., 1997). Another reason why Mg in water can play a critical role has in its bioavailability. Mg in water is more easily adsorbed than Mg in food (Durlach at al., 1989; Theophanides et al., 1990). The contribution of water Mg to the diet of person who use water with high Mg level could, thus, be crucial in the prevention of Mg deficiency (Rubenowitz et al., 1996). It seems that the theory of the protective effect Mg from drinking water is gaining more confirmation in practice and experiment. This is supported by knowledge of the function of Mg. Its pathophysiological and clinical importance in cardiovascular risk has been reviewed by Durlach et al. (1989).

Cardiovascular diseases, including cerebrovascular accidents (strokes), account for more than half the death in Serbia (55.7% in 1995; Djordjević et al. 1998). The aim of this paper was to study the relationship between CVD mortality in this country and the hardness of drinking water.

METHODS

During the summer 1998 the water samples from 65 municipalities in Serbia, including the sity of Belgrade, were collected and analyzed for Mg^{2+}, Ca^{2+}, Na^+, K^+, and Cl^-, SO_4^{2-} and HCO_3^-; the pH and dry residue 180° C were also determined, and water hardness calculated. Chemical analyses were done by volumetric, spectrophotometric and flamephotometric methods.

RESULTS AND DISCUSSION

Results of Mg and Ca levels in drinking water, hardness of drinking water, as well as CVD mortality rates in Serbia, are presented in Figs. 1–4, and Table 1.

Table 1. Ca, Mg, Na and K in drinking water and water hardnes in relation to CVD mortality rates in Serbia

Region	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Ca/Mg	Hardness ($CaCO_3$)	CVD mortality
Banat, N. Serbia	61.0	19.5	131.5	1.4	2.8	231	1015
Bačka	56.2	31.1	58.0	1.5	2.1	268	889
Srem	70.1	37.7	44.0	1.0	2.0	330	742
Bor–Zaječar	89.5	8.8	7.0	1.2	13.7	260	862
Pirot, E. Serbia	93.2	3.9	1.7	0.4	24.0	249	990
Toplica, S. Serbia	33.7	12.4	6.0	1.9	3.2	136	927
Zlatibor	9.0	49.0	1.7	0.6	0.2	223	578
Raška, W. Serbia	47.3	68.0	8.0	2.0	0.9	398	561
Kolubara	95.4	3.1	1.7		37.9	251	785
Pomoravlje	114.8	15.9	11.5	1.5	11.0	352	772
Mačva	103.0	18.8	9.1	1.0	6.8	335	688
Belgrade area	71.2	18.2	34.5	1.6	3.9	253	586

Mg content is very variable in drinking water (Fig. 1), from 0–>10 mg/L to 40–>80 mg/L. The lowest levels of Mg were found especially in the Eastern Serbia, where are dominant limestones of different age. The highest levels of this element occur in the Zlatibor Mt. region and in the Raška area, where ultramafic rocks rich in Mg are very abundant.

Ca content is less variable in drinking water then Mg (Fig. 2), mostly between 40 to <80 mg/L and >80 mg/L. The highest values were obtained especially in the Eastern Serbia, where limestones are very abundant.

Calculated hardness of drinking water is mostly hard (150–300 mg/L) or very hard (>300 mg/L) in the communities in Serbia (Fig. 3). According to data obtained it is not possible to get some relatioship with the CVD mortality (Fig. 4).

Results for Mg and Ca levels and hardness of drinking water in Serbia are given for 65 communities, but CVD mortality is given for all districts, which are larger units. Therefore, it is difficult to compare the results obtaind. However, it is possible to get some preliminary conclusions.

The first region comprises nothern Serbia – the areas of Banat, Bačka and Srem. The average analyses show a moderate Ca content from 56.2 to

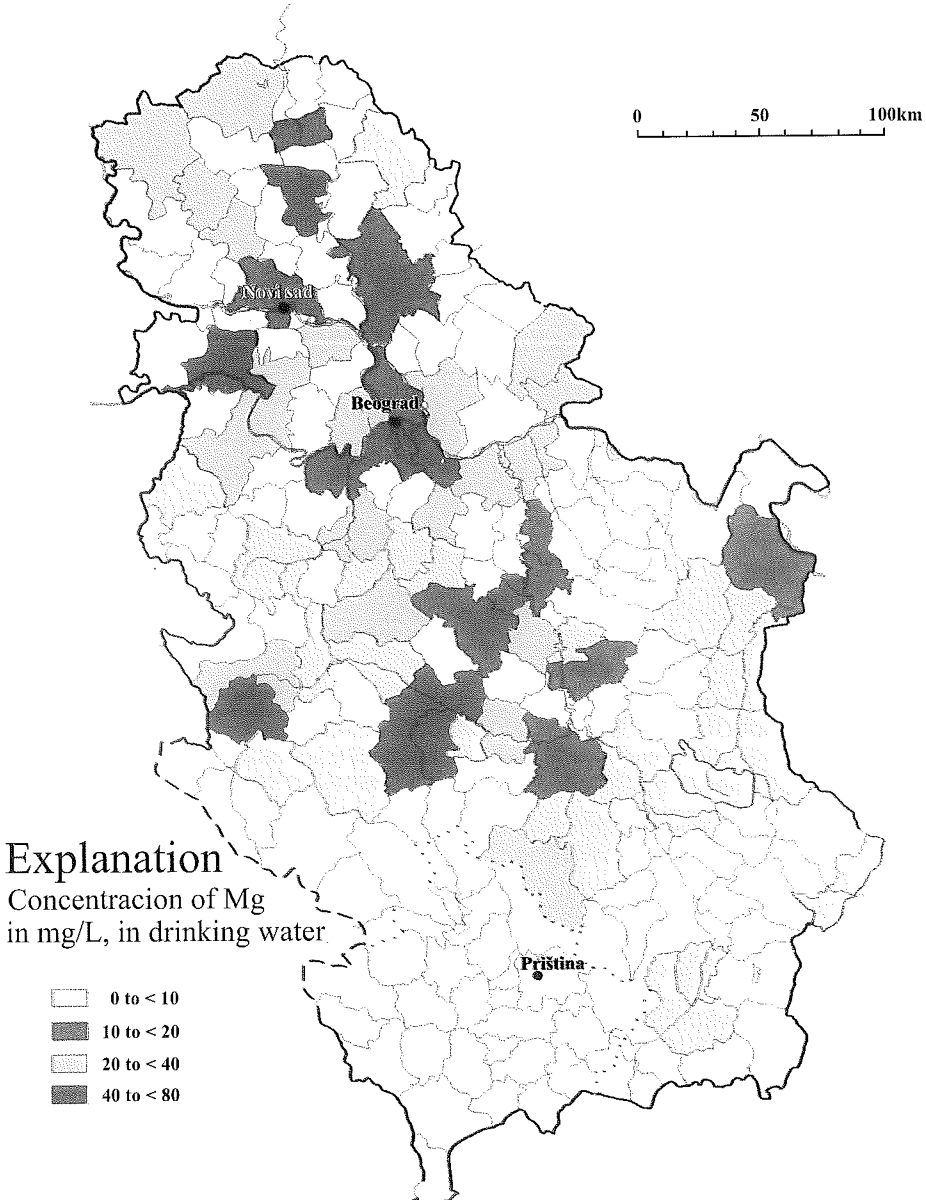

Fig. 1. Magnesium in drinking water in Serbia

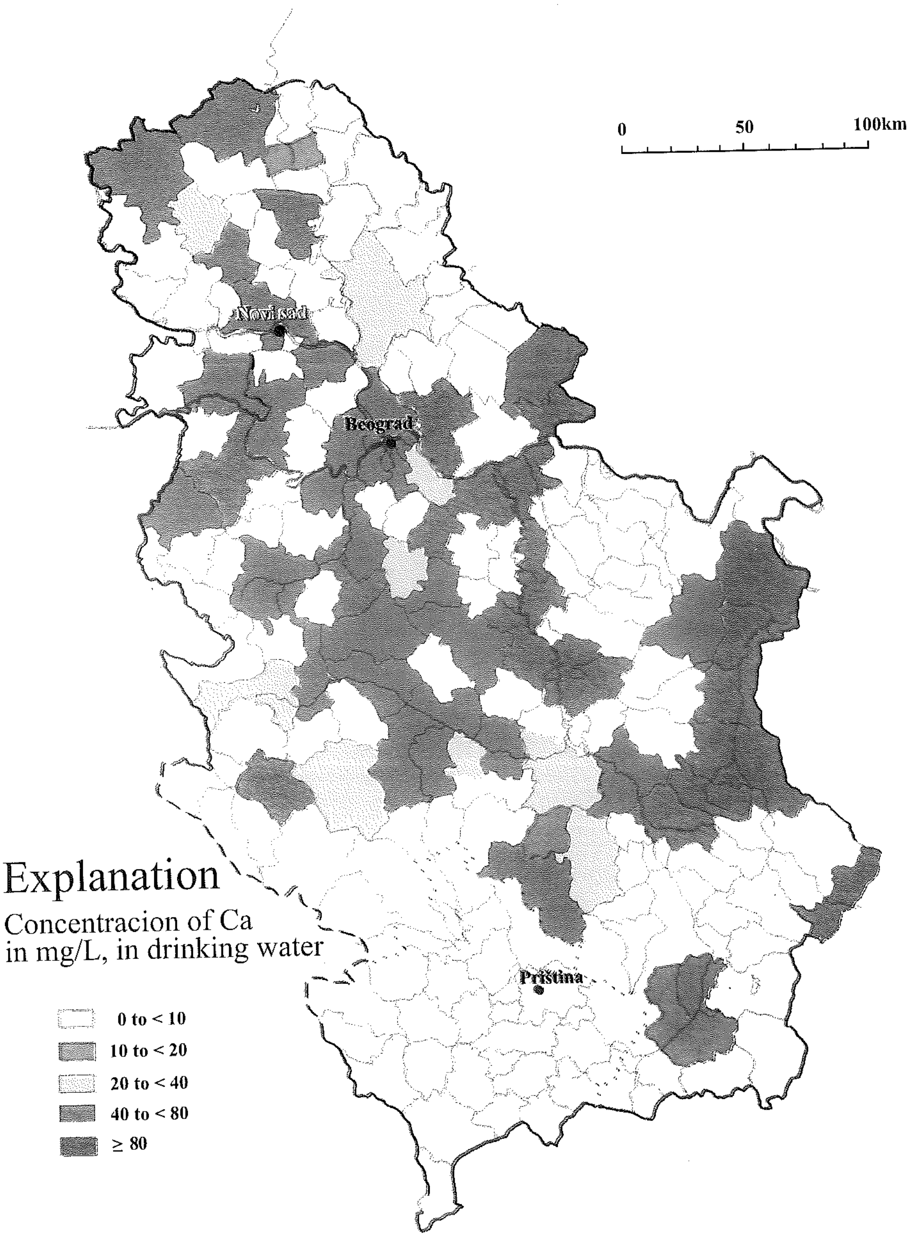

Fig. 2. Calcium in drinking water in Serbia

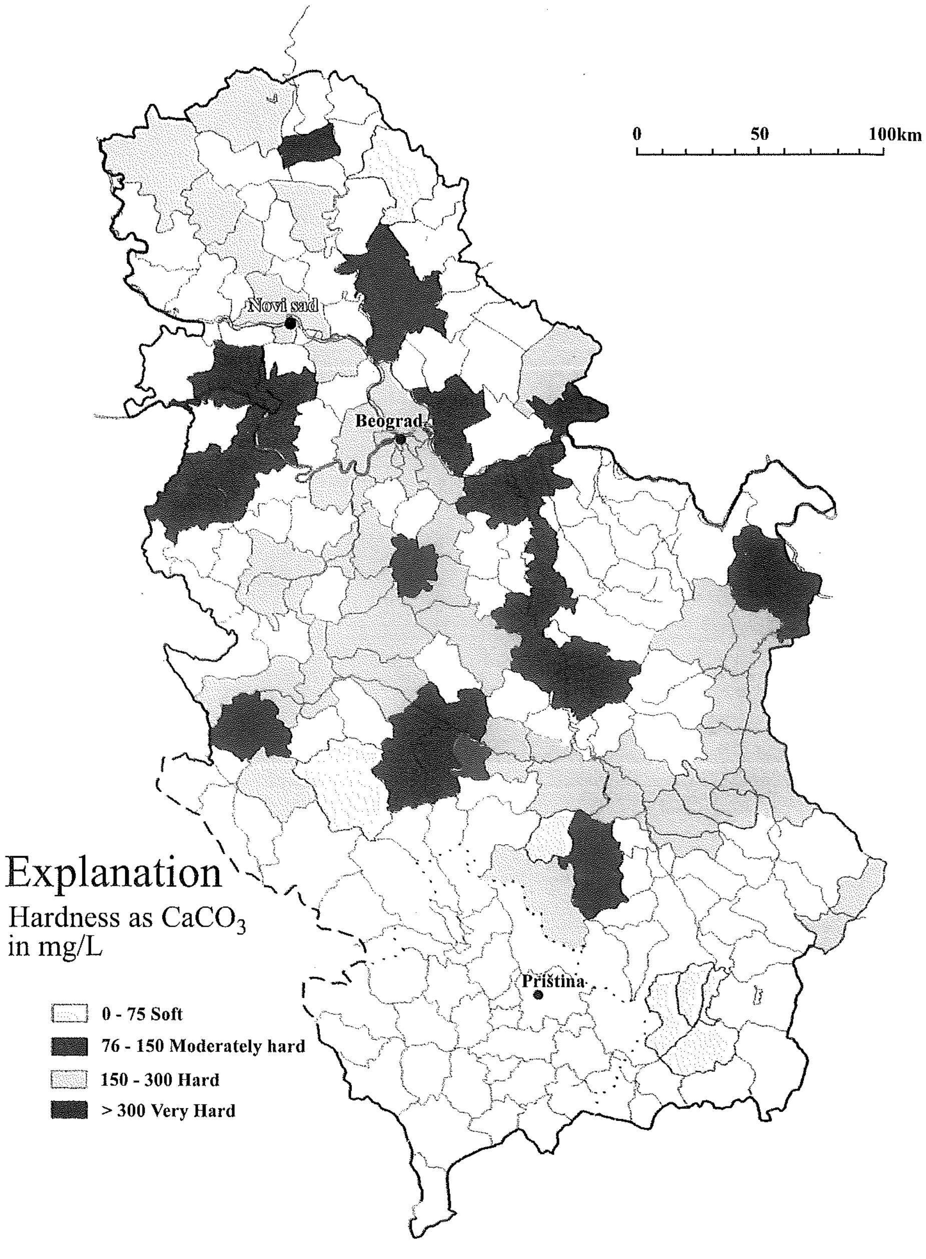

Fig. 3. Hardness of drinking water in Serbia

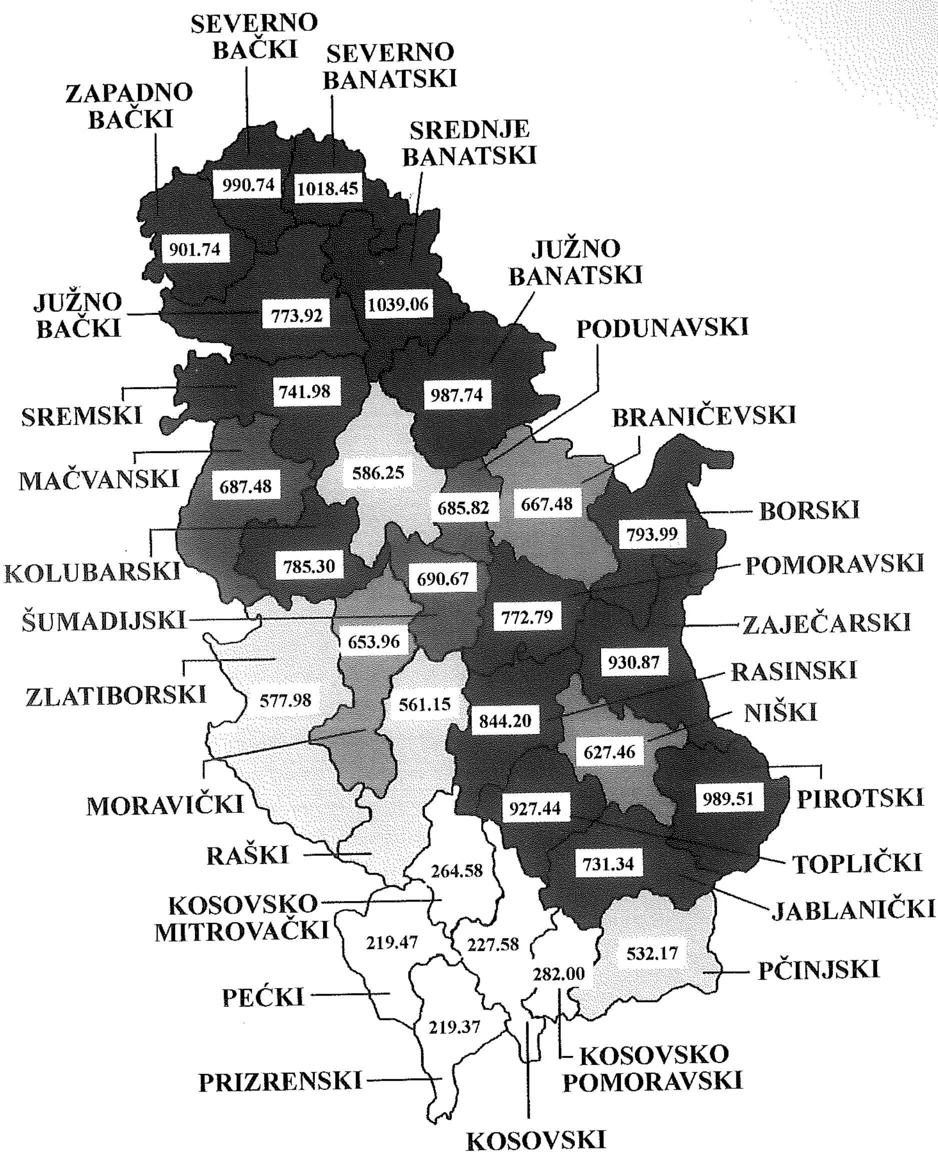

Fig. 4. Cardiovascular mortality rates in districts of Serbia (Djordjević et al., 1998)

70.1 mg/L, and Mg from 19.5 mg/L in Banat to 37.7 mg/L in Srem (Table 1). The water hardness is ranking from hard to very hard. According to these values, the CVD mortality should be relatively low. However, in this region of northern Serbia (Vojvodina), comprising the Panonian plaines, which are the main food producer of this country, CVD mortality is one of the highest in Serbia (Fig. 4). This is an example of influence of other factors in the etiology of CVD, which hardly may include only effects of drinking water. The CVD mortality decreases from Banat through Bačka to Srem in the direction of increasing Mg content and water hardness. It should be mentioned, however, that Na is relatively high in these waters: 131.5 mg/L in Banat 50 mg/L in Bačka and 44 mg/L in Srem, decreasing in the direction of decreasing CVD mortality. The content of Na, as an alkaline element, is not included in the water hardness. However, the high level of Na in drinking water in the northern Serbia related to the high CVD mortality needs further study.

The second region in Table 1 comprises Bor–Zaječar districts in the Eastern Serbia and Toplica district in the Southern Serbia. The drinking water is characterized by very low Mg content, from 3.9 to 12.4 mg/L. The Ca content is high in the Bor–Zaječar–Pirot district, resulting in very high Ca/Mg ratios, 13.7 to 24.0. In these districts the water is hard due to high Ca content. In the Toplica district the water is soft, due to low content both Ca and Mg. The CVD mortality in these districts is one of the highest in Serbia, from 862 to 927 (per 100.000)(Fig. 4). Besides other possible etiological factors, these districts are characterized by very low Mg levels in the drinking water, including a very high Ca/Mg ratio. This is a good example of the negative association between CVD mortality and the Mg level in drinking water. On the other hand, water hardness due to a very high Ca content does not seem to have a negative relationship with CVD mortality.

The third region includes the Western Serbia, with Zlatibor and Raška districts. They are characterized by relatively high Mg levels in the drinking water, from 49.0 to 68.0 mg/L, the lowest Ca/Mg ratio (below 1) and very hard water. These districts have the lowest CVD mortality in Serbia, 561 to 578 per 100.000. This is a good example demonstrating a negative association between CVD mortality and water hardness due to high Mg content.

The other regions in Table 1, including the Kolubara, Pomoravlje and Mačva districts, are characterized by high Ca levels in the drinking water (95.4–114.8 mg/L), low Mg (3.1–18.8 mg/L), very high Ca/Mg ratio (6.8–17.9) and hard to very hard drinking waters. The CVD mortality is relatively high and shows a decrease from Kolubara district (785), through Pomoravlje (772) to Mačva (687.5), following a decrease of the Ca/Mg ratio. It seems that a hard water with high Ca and low Mg content does not support a low CVD mortality.

The Belgrade area is characterized by a low CVD mortality (586) compared with most of the other regions in Serbia. The reason for this extends beyond the drinking water quality. However, in this area drinking water has a moderate Ca level (71.2 mg/L), and not so low Mg content (18.2 mg/L), and relatively convenient Ca/Mg ratio (3.9). These data are in accordance with published chemical characteristics of ground waters used for the water supply system of the Belgrade area (Dimitrijević and Bucalo, 1998). From 20 representative reni-wells, in 11 of them content of Mg was between 20 and 46 mg/L.

Two theories have been offered concerning the causative agent for the relatioship between CVD death and water hardness. Soft water is more corrosive than hard water, and promotes the dissolution of Cd, Pb and other toxic substances from the plumbing system into drinking water (Westendorf and Middleton, 1979). Another theory is that there is a protective effect of Mg from drinking water (Karppanen, 1986; Marier, 1986; Durlach et al., 1989). Recent papers indicate that the high Ca/Mg ratio in drinking water (5/1 and more) has been implicated in the high Finnish heart attack and stroke rates (Franz and Seeling, 1998). Our data support tha possibility that a high Ca/Mg ratio in drinking water could play a role in the multifactorial etiology of CVD.

CONCLUSIONS

The results obtained give the following indications:

1. The municipalities with drinking water very poor in Mg (<10 mg/L) but rich in Ca (>80 mg L), have very high CVD mortalities (for example, the Eastern Serbia).

2. The regions with drinking water relatively rich in Mg (52.2–68.0 mg/L), but poor in Ca (3.5–12.4 mg/L), have a very low CVD mortality rate (Zlatibor area, Raška, Western Serbia).

3. In the Northern Serbia (Vojvodina), where the CVD mortality is very high, drinking water has relatively low Mg and moderate Ca content. This province, however, is characterized by a high level of Na in the drinking water. It seems that very high CVD mortality is extended beyond the drinking water quality.

A negative relationship between CVD mortality and the Mg level in drinking water is indicated, with the possibility that the Mg concentration in water is part of the etiological mosaic of CVD. The hardness of water alone, with high Ca and very low Mg content seems to have positive relationship with CVD mortality.

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