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ORIGINAL PAPER

The potential impact of geological environment on health status of residents of the Slovak Republic

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Abstract In order to assess the potential impact of the geological environment on the health of the population of the Slovak Republic, the geological environment was divided into eight major units: Paleozoic, Crystalline, Carbonatic Mesozoic and basal Paleogene, Carbonatic-silicate Mesozoic and Paleogene, Paleogene Flysch, Neovolcanics, Neogene and Quaternary sediments. Based on these geological units, the databases of environmental indicators (chemical elements/parameters in groundwater and soils) and health indicators (concerning health status and demographic development of the population) were compiled. The geological environment of the Neogene volcanics (andesites and basalts) has been clearly documented as having the least favourable impact on the health of Slovak population, while Paleogene Flysch geological environment (sandstones, shales, claystones) has the most favourable impact. The most significant differences between these two geological environments were observed, especially for the following health indicators: SMRI6364 (cerebral infarction and strokes) more than 70 %, SMRK (digestive system) 55 %, REI (circulatory system) and REE (endocrine and metabolic system) almost 40 % and REC (malignant neoplasms) more than 30 %. These results can likely be associated with deficit contents of Ca and Mg in groundwater from the Neogene volcanics that are only about half the level of Ca and Mg in groundwater of the Paleogene sediments.

Keywords Geochemical background · Environmental indicators · Health status · Health indicators · Slovak Republic

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Introduction

The association of rocks and minerals and human health has been known since antiquity. Each natural substance, a mineral or a chemical element, can be

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harmful or helpful to health depending on the dosage (Paracelsus), speciation and route of exposure. Thus, either excess exposure to potentially toxic elements (e.g. arsenic, mercury and radon) or the lack of essential chemical elements (e.g. iodine, selenium, zinc and magnesium) can account for possible detrimental health effects.

According to the WHO's Universal Declaration, the health status of a population is mainly influenced by the lifestyle (the way we live and work) accounting for up to a 50 % portion of population health on average. The next three significant factors—the environment, the level of medical care and genetic factors—each account for between 10 and 20 % of population health (www.who.int). Nevertheless, the impact of the environment in heavily contaminated or geologically unfavourable areas may exhibit a noticeable impact on the health of the people in the region.

Nowadays, the relationship between the concentration of potentially toxic elements in the geological component of the environment and human health is widely recognized, documented and assessed in many scientific articles, studies and monographs (e.g. Selinus et al. 2005; Dissanayake and Chandrajith 2009; Brevik and Burgess 2013). The most commonly cited examples of health problems caused by a naturally occurring trace element are studies dealing with the excess exposure to arsenic (Smedley and Kinniburgh 2002; Duker et al. 2005). Other works dealing with the impact of either the deficit or the excess of various chemical elements in geological environment, especially iodine, fluorine and selenium include, for example, WHO (2002, 2004), El-Bayoumy (2001), Takahashi et al. (2001), and Vinceti et al. (2010). Many studies of similar character were summarized, in the monographs by Selinus et al. (2010, 2013). However, no comprehensive research has been carried out so far focusing on the health impacts of a wide range of naturally occurring chemical elements (macro-components and potentially toxic elements) from a single geographic region. This paper represents the first attempt to deal with the comprehensive evaluation of such a wide range of environmental and health indicators. We did not find any literature available of a similar character. Therefore, we have tried to develop the methodological procedures for such a comprehensive elaboration of data on environmental and health indicators and applied them on a national level for the Slovak Republic.

Extensive environmental geochemical mapping of the Slovak Republic, in particular the geochemical atlases (Vrana et al. 1997) and environmental geochemical maps (Rapant et al. 1999) projects, was considered as the basis for compilation of the national geochemical database for the Slovak Republic. Moreover, these studies also served as a starting point for an expert study of the potential harmful impacts of the geological environment on human health. The Environmental and Health Indicators of the Slovak Republic (Rapant et al. 2010) should be considered as a nationwide pilot project of medical geology. This work includes a unified database of environmental indicators (chemical elements and parameters in groundwaters and soils) and demographic development and health status indicators for each of 2,883 municipalities of the Slovak Republic. The set of maps and databases compiled in this unified way is an excellent basis for the environmental studies that follow as well as assessment of the health status of Slovak inhabitants. The main objective of this current study was to determine the association of diverse geological environments and the health of the inhabitants. In other words, we intended to find out whether the differences in the geochemical background are reflected in the health status of the Slovak population.

Materials

Environmental indicators

The environmental indicators are the contents of chemical elements/compounds analysed and measured in the environment (Rapant et al. 2010). In this study, we evaluate environmental indicators in groundwater and soil. These two components of the geological environment can exert a significant impact on human health.

Groundwater is the most important source of drinking water for most people. In Slovakia, it is used as the source of drinking water for more than 90 % of the inhabitants (Klinda and Lieskovská 2010). The soil is the base of the food chain and represents that part of the environment where human life directly takes place. The crops we eat are grown in the soil; the meat, eggs and milk that we consume are derived from animals that graze on the soil; children and some adults even eat the soil. The soil chemistry, as well as

Table 1 Characteristics of environmental indicators for the Slovak Republic (mean values)

Groundwater (n = 20,339)												
pH	MIN	$ChSK_{Mn}$	Ca + Mg	Li	Na	K	Ca	Mg	Sr	Fe	Mn	NH_4
7.33	629.75	2.18	3.5	0.019	20.34	11.10	93.56	28.29	0.36	0.17	0.12	0.10
F	Cl	SO_4	NO_2	NO_3	PO_4	HCO_3	SiO_2	Cr	Cu	Zn	As	Cd
0.13	32.96	79.32	0.11	38.76	0.20	303.85	18.21	0.0013	0.0026	0.2673	0.0019	0.0010
Se	Pb	Hg	Ba	Al	Sb							
0.0010	0.0014	0.0001	0.0747	0.0297	0.0009							

Soils (n = 10,738)												
Al[a]	As	B	Ba	Be	Bi	Ca[a]	Cd	Ce	Co	Cr	Cu	F
5.90	12.45	65.03	392.78	1.39	0.41	1.46	0.60	64.65	11.77	87.55	26.15	330.98
Fe[a]	Hg	K[a]	Mg[a]	Mn[a]	Mo	Na[a]	Ni	P[a]	Pb	Sb	Se	Sn
2.71	0.24	1.70	0.87	0.08	0.68	0.85	29.29	0.07	29.62	3.69	0.16	4.71
Sr	V	W	Zn	pH_{H2O}	pH_{KCl}	Carbonates[a]						
101.38	79.07	0.92	75.79	6.26	5.52	2.45						

Data except of pH in mg l^{-1}

[a] Macro-components in %, microcomponents in mg kg^{-1}

the groundwater chemical components, is determined as "total contents" (by the sampling and digestion methods and chemical analysis according to Rapant et al. 1996; Čurlík and Šefčík 1999). This set of environmental indicators and their mean values for the Slovak Republic groundwater and soil is displayed in Table 1.

The total number of geochemical analyses for groundwater was 20,339 and for soils 10,738. These include the analyses that have been collected since 1991, when the modern environmental geochemical mapping of the Slovak Republic started under the IGCP 360 Geochemical Correlation Programme (Darnley et al. 1995). The density of groundwater samples was about one sample per 2.5 sqkm and of soil samples about one sample per 5 sqkm.

Health indicators

The health status of the Slovak Republic population was evaluated based on health indicators. A health indicator is a variable that can express the health status of people in society via direct measurement or observation (Last 2001). Its main importance relies on local and time comparability. However, we can say whether the assessed health is good or bad, only when a number of areas or time periods are subject to evaluation. In addition, health indicators must be compared to each other or to standard or published values for larger units. There is no single comprehensive indicator which would capture all or the majority of aspects of population health status. Therefore, a relatively large set of multiple indicators was used in this study.

With regard to sensitivity and, especially, diversity of the data, there is the need for a longer period of time in which health indicators are carefully monitored and evaluated. In our study, we used a ten-year period (1994–2003), which still may not be sufficient, particularly concerning small-sized villages. The health indicator data were received from the database of the Statistical Office of the Slovak Republic and are guaranteed by the government (www.statistics.sk). We used only the data describing demography and mortality. The data evaluating the incidence of various diseases are not available.

To assess the health status of the Slovak population in relation to the environment, 30 health indicators were selected. It is expected that these indicators can be mostly affected by the geological environment. The review of assessed health indicators is given in Table 2 along with nationwide average values (Rapant et al. 2010).

The selected health indicators describe relevant information on age, reproductive health, and, particularly, information on different types of mortality. We

Table 2 The list of 30 selected health indicators

Abbr	Contents	Block	Unit	SR
LEm	Life expectancy at birth (men)	Age characteristics	Years	67.44
LEw	Life expectancy at birth (women)		Years	77.07
A60+	Proportion of population at age 60 and more		%	15.38
A85+	Proportion of population at age 85 and more		%	0.84
BIR	Birth rate	Reproduction healths	‰	10.58
GFR	General fertility rate		‰	46.15
LBW	Low birth weight rate (LBW below 2,500 g)		%	7.55
SAR	Spontaneous abortion ratio		‰	62.98
CMm	Crude mortality rate (men)	Mortality	‰	14.76
CMw	Crude mortality rate (women)		‰	9.07
SMRp	Indirect standardization: standardized mortality ratio (population)		%	100
SMRm	Indirect standardization: standardized mortality ratio (men)		%	100
SMRw	Indirect standardization: standardized mortality ratio (women)		%	100
PPDm	Proportion of premature deaths—men (under 65)	Premature mortality	%	33.67
PPDw	Proportion of premature deaths—women (under 65)		%	17.53
PPDNCp	Proportion of premature deaths—natural causes (under 65)		%	23.37
PYLL1 m	PYLL per 1 man death (potential years of life lost)		Years	4.68
PYLL1w	PYLL per 1 woman death		Years	2.19
PYLL100	PYLL per 100,000 of population		Years	4,033
PYLLC	PYLL due to malignant neoplasms per 100,000 of population		Years	1,005.20
REC	Deaths per 100,000, malignant neoplasms	Deaths rate per 100,000	No. of deaths per 100,000 inhabitants	212.79
REE	Deaths per 100,000, endocrine, nutritional and metabolic diseases		No. of deaths per 100,000 inhabitants	14.43
REI	Deaths per 100,000, diseases of the circulatory system		No. of deaths per 100,000 inhabitants	531.05
SMRC	Standardized mortality ratio—malignant neoplasms	Indirect age-standardized mortality	%	100
SMRC1526	Standardized mortality ratio—malignant neoplasms of digestive organs		%	100
SMRC3039	Standardized mortality ratio—malignant neoplasms of respiratory and intrathoracic organs		%	100
SMRI2125	Standardized mortality ratio—ischaemic heart diseases (myocardial infarction and chronic ischaemic heart disease)		%	100
SMRI6364	Standardized mortality ratio—cerebral infarction and strokes		%	100
SMRJ	Standardized mortality ratio—diseases of the respiratory system (no neoplasms)		%	100
SMRK	Standardized mortality ratio—diseases of the digestive system (no neoplasms)		%	100

SR average value for Slovak Republic

have deliberately chosen only robust indicators that are stable, not rare and do not alter suddenly. Out of the 30 health indicators subject to assessment, we can set aside first six of them as positive, meaning that the most favourable values are the highest values. The other 24 health indicators can be assigned as negative, meaning that their most favourable values should be as low as possible, even reaching zero values.

Methods

Processing of environmental indicators

When processing and calculating the environmental indicators, we adopted a method of geochemical data processing and representation of environmental indicators so that they can be united with the health indicators. Therefore, we had to transform the environmental indicators into a form compatible with the health indicators, which represented an administrative unit of the Slovak Republic—a village or a district. Transformation of the geochemical data (chemical composition of soils and groundwater) was compiled in the same way. Thus, the environmental indicators were calculated for the basic territorial units of the Slovak Republic—municipalities and then districts, higher territorial units as well as for the entire Slovak Republic. Calculations of environmental indicators represented a determination of the average value of an element/parameter for the evaluated territorial administration unit based on the contents of all soils and waters found in the unit.

The calculation procedure was as follows. A pixel map of spatial distribution of elements and components was compiled from all the input data for the entire Slovak Republic using the MapInfo Professional 9.0 software. The search factor was 1, function power 2, while anisotropy of the environment was not involved. The basic map cell is a square or a pixel with a one kilometre side, i.e. a pixel area is 1 sqkm. For each pixel, a corresponding average value of element concentration was computed based on inverse distance from the pixel centre to the nearest ten samples. Grid average value of environmental indicators for specific administration units (villages, districts and higher territorial units) was then calculated as the arithmetic mean value from the values of the contents for each pixel falling under the administration units. In addition, pixel values concerning the involved administration units were only partially included in the calculation. This calculation method of the environmental indicators provides a more objective evaluation of the content of elements found in the observed administration units, since the distribution of the elements is taken into account regardless of any administrative boundaries and the element contents are also interpolated beyond administrative boundaries.

All the calculations of environmental indicators were processed both in a numerical as well as map form for each of 2,883 municipalities, 79 districts, 8 higher territorial units and for the whole territory of the Slovak Republic.

Processing of health indicators

All health indicators were calculated as a cumulative function for the years 1994–2003, i.e. for a ten-year period, when all cases were summed up and all numbers of inhabitants were taken as persons-per-years (number of inhabitants as of December 31 in a pertinent year) for each territorial unit assessed.

Calculation methodology and standardization of health indicators were carried out according to recommendations of WHO; Beaglehole et al. (1993); Jenicek (1995); Last (2001).

Health indicators are classified according to WHO International Classification of Diseases (ICD, 10th revision, www.who.int/classifications/icd/en/). Accurate calculation methods or formulas used to calculate individual health indicators are given in Table 3.

Classification of geological structure

From a geological perspective, the territory the Slovak Republic is part of the Western Carpathians. The development of the territory was shaped by geological processes in three Wilson cycles as follows: Cadomian-Caledonian, Hercynian and Alpine. As a result of multiple tectonic processes, the Western Carpathians are an area with one of the most complicated geology. In a very small area, the Western Carpathians form a "puzzle" of Paleozoic rocks, Crystalline, Mesozoic, Paleogene and Neogene rocks in thrust and fault tectonics, being often masked by Quaternary sediments (Kohút et al. 1999). Geological maps of the Slovak Republic are available in different scales on the

Table 3 The method of calculation of health indicators

Indicator abbreviation	Brief calculation description; formula
LEm LEw	The cumulative calculation of all years of life during lifetime/No. of inhabitants living at the beginning of the year (men/women)
A60+	100 × (number of people aged 60 and over/number of inhabitants)
A85+	100 × (number of people aged 85 years and over/number of inhabitants)
BIR	1,000 × (number of live births/number of inhabitants)
GFR	1,000 × (number of live births/number of women aged 15 to 44 years)
LBW	100 × (number of newborns with a birth weight of 2,500 g/number of newborns
SAR	100 × (number of live births/total conception)
CMm	1,000 × (number of deaths in men/number of men)
CMw	1,000 × (number of deaths in women/number of women)
SMRp	Indirect age-standardized mortality rate of inhabitants, standardized to the Slovak standard (19 age groups)
SMRm	Indirect age-standardized mortality rate of men, standardized to the Slovak standard (19 age groups)
SMRw	Indirect age-standardized mortality rate of women, standardized to the Slovak standard (19 age groups)
PPDm	100 × (number of deaths in men aged between 1 to 64 years)/number of male deaths
PPDw	100 × (number of deaths in women aged between 1 to 64 years)/number of female deaths
PPDNCp	100 × (number of natural deaths in inhabitants age between 1 to 64 years)/number of male deaths
PYLL1 m	Potential years of life lost in men before 65 years of age (deaths at age between 1 to 64 years)/number of male deaths
PYLL1w	Potential years of life lost in women before 65 years of age (deaths at age between 1 to 64 years)/number of female deaths
PYLL1C	100,000 × (the sum of the years of people up to the age of nearly 65 years (deaths at age 1 to 64 years) due to malignant neoplasms/number of inhabitants
PYLL100	100, 000 × (the sum of the years of people up to the age of nearly 65 years (deaths at age between 1 to 64 years)/number of inhabitants
ReC	100,000 × (number of deaths from malignant neoplasms—C00-C97/number of inhabitants
ReE	100,000 × (number of deaths from endocrine, nutritional and metabolic diseases—E00-E90/number of inhabitants
ReI	100,000 × (number of deaths from diseases of circulatory system (I00-I99/number of inhabitants
SMRC	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—malignant neoplasms
SMRC1526	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—malignant neoplasms of digestive organs
SMRC3039	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—malignant neoplasms of respiratory organs
SMRI2125	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—ischaemic heart diseases
SMRI6364	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—cerebral infarction and strokes
SMRJ	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—diseases of the respiratory system
SMRK	Indirect age-standardized mortality, standardized to a Slovak standard (19 age groups)—diseases of the digestive system

website of the State Geological Institute of Dionýz Štúr (ŠGÚDŠ) at www.geology.sk. The mineralogical and petrographic character of the rock environment, i.e. its geochemical background, was considered the main criterion for classification of the geological structure of the territory of the Slovak Republic. Thus, in the cases of some units, the geological and tectonic subdivision of geological structure of Slovakia was not respected. The territory of the Slovak Republic has been categorized into eight units as follows:

1. Paleozoic: mostly metasediments, metavolcanics,
2. Crystalline: mostly granites, gneisses and migmatites,
3. Carbonatic Mesozoic and basal Paleogene: mainly limestones, dolomites, carboniferous conglomerates,
4. Carbonatic-silicate Mesozoic and Paleogene: mainly marl, marly limestones, dolomites, sandstones and shales,
5. Paleogene Flysch: mainly sandstones, shales, claystones,
6. Neovolcanic rocks: mainly andesites, basalts and their volcanoclastics,
7. Neogene: mainly clays, claystones, conglomerates, sands, gravels,
8. Quaternary: mainly gravel, sand, clay, rock fragments.

Categorization of the geological structure of the territory of the Slovak Republic according to municipal land registers is shown in Fig. 1. For about 50 % of the Slovak municipalities, mainly in the Paleogene Flysch rock environment, Neogene volcanic rocks and Quaternary sediments, the geological structure classification based on municipal land registers was not found to be problematic. The crucial part of the municipalities in these geological formations, including the location of settlements, was primarily built on only one geological unit. Similarly, it was quite easy to attribute the geological environment to municipalities located in foothill areas, built on the core mountains and proluvial-deluvial Quaternary sediments. In this case, the municipalities were assigned a mountainous character of proluvial-deluvial Quaternary rocks, which from the mineralogical and petrographic, and thus also from the geochemical point of view, was similar to the older geological formations. Approximately 25 % of the municipalities are located in different geological formations. In the case of these villages, the geological location of the settlements was among the key criteria for their categorization. Moreover, we have also taken into consideration helpful geochemical criteria—contents of the chemical elements in groundwater and soils as well as geomorphology. However, because of complexity of the geological structure, we have not been able to assign a geological environment to 51 municipalities. We have excluded from further evaluation these municipalities along with so-called military districts with anomalous population.

Based on the prevailing geological structure, we have sorted the data of environmental (groundwater, soil) and health indicators according to the geological units described above. Consequently, the average values of environmental and health indicators were calculated, including arithmetic means and medians. Since no significant difference between these two values (arithmetic means and medians) was reported, only the arithmetic values were used in further evaluation.

We observed health impacts of contamination by potentially toxic elements on the population of the Slovak Republic in three historic mining areas as follows—Slovak Ore Mts., Central Slovak Neovolcanics and the Upper Nitra region (Fig. 2). In these three areas, we designated contaminated (138 municipalities) and noncontaminated (155 municipalities) localities based on the content of potentially toxic elements. The areas of the Slovak Ore Mts. and the Central Slovak Neovolcanics have been contaminated mainly due to the mining industry over the last few centuries, while the Upper Nitra region has been polluted particularly as a result of brown coal mining and combustion (from a coal-burning power station as well as household use) and the high contents of arsenic in the brown coal.

Results

The average values of health indicators of the Slovak population classified according to the geological structure (based on the municipal land registers) are listed in Table 4. The average values of the environmental indicators (based on municipal land registers) for groundwater are shown in Table 5 and for soils in Table 6. Selected values of environmental and health indicators of the three contaminated areas compared with three adjacent noncontaminated areas of similar geological, geomorphological and socio-economic character are also given in Table 7. For comparison, Table 8 presents the values of environmental and health indicators of two Slovak districts. Krupina district is geologically built only on rocks of Neogene volcanics (in terms of health indicators, it is the least favourable geological environment). Bardejov district is built only on rocks of Paleogene Flysch (in terms of health indicators, it is the most favourable geological environment).

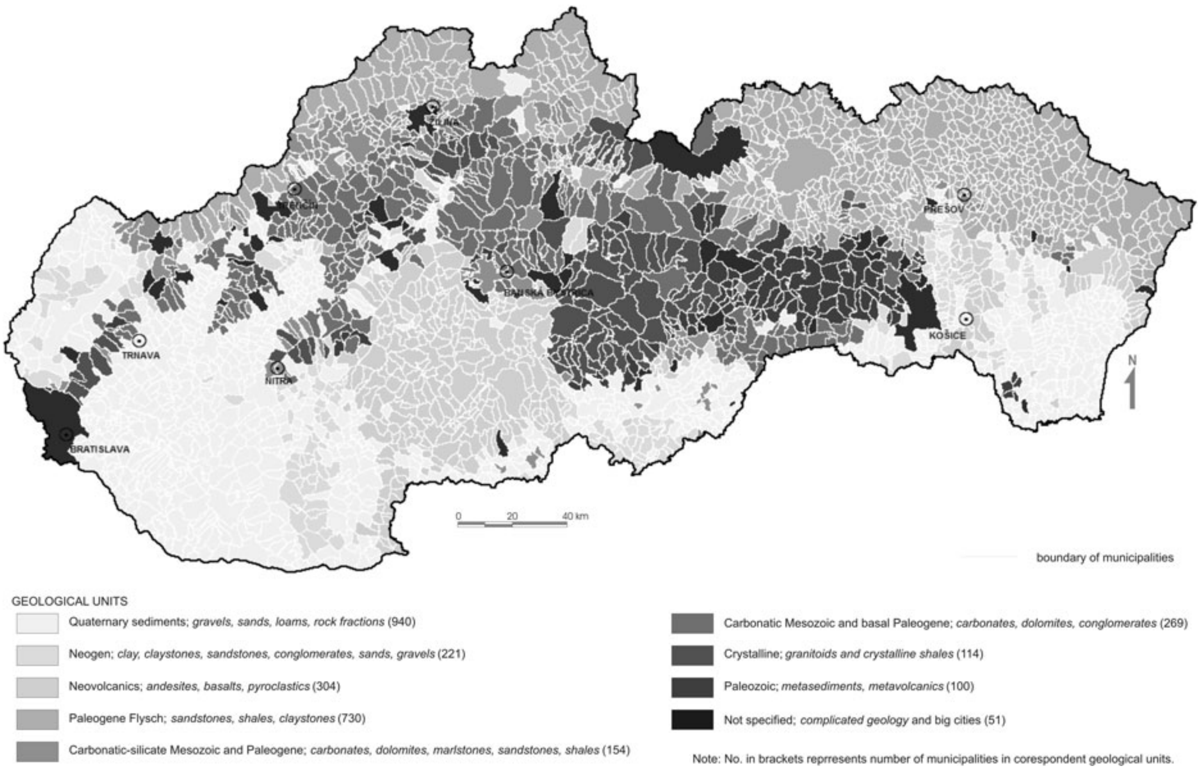

Fig. 1 Division of geological structure of the Slovak Republic in main geological units

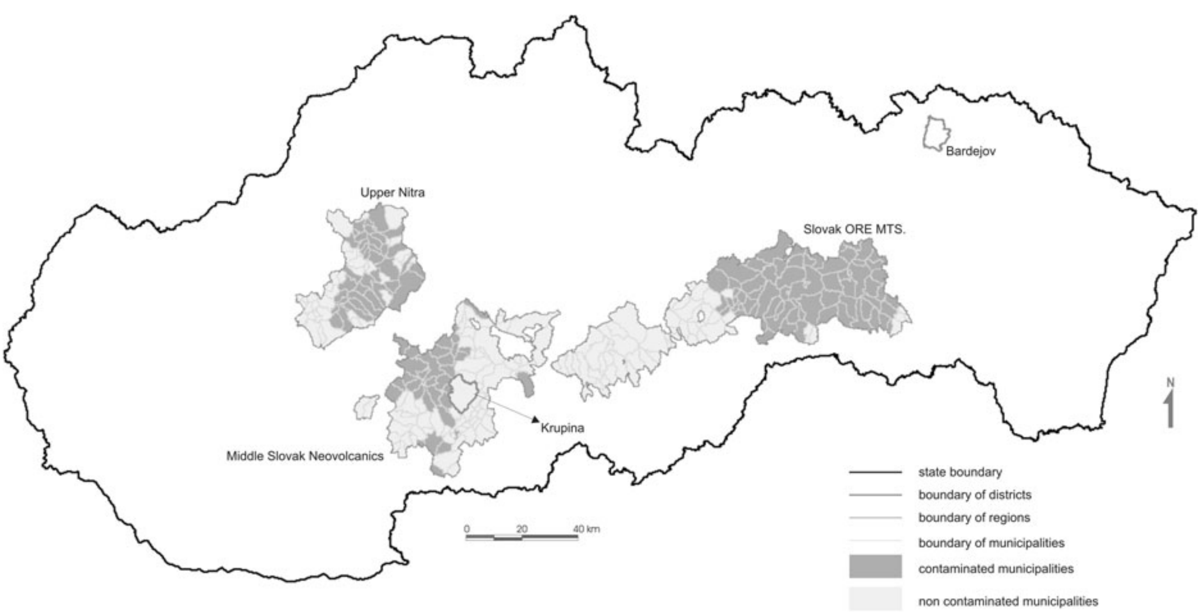

Fig. 2 Contaminated and noncontaminated areas of the Slovak Republic

Table 4 Health indicators for the population of the Slovak Republic according to geological units (mean values calculated for administrative units, according the number of inhabitants)

Geological unit	1	2	3	4	5	6	7	8
Altitude	424.75	466.55	412.54	340.19	412.40	332.93	226.57	173.23
No. of inhabitants	1,489	2,319	1,341	1,838	1,437	1,155	1,072	1,871
LEm	66.42	67.05	68.37	67.49	68.59	65.88	67.85	67.86
LEw	75.81	75.85	77.04	77.35	78.15	75.58	76.82	75.15
A60+	15.26	15.87	16.82	14.79	13.64	16.88	17.64	15.84
A85+	0.80	0.85	0.97	0.82	0.74	0.97	1.07	0.86
BIR	12.03	9.93	10.41	10.32	13.18	10.15	11.22	10.12
GFR	54.44	43.78	47.48	45.11	59.02	45.96	51.75	44.49
LBW	8.64	6.50	5.24	5.49	6.31	6.58	7.37	6.67
SAR	67.12	59.76	62.59	61.65	77.11	58.95	60.24	58.55
CMm	13.29	13.50	13.92	12.29	11.25	15.44	15.31	13.71
CMw	10.22	9.87	10.40	9.31	8.38	11.74	11.82	10.51
SMRp	108.32	101.03	98.39	97.99	98.48	108.05	105.62	104.63
SMRm	109.60	102.50	100.22	97.63	99.27	111.07	106.84	104.47
SMRw	108.43	99.43	96.02	98.85	97.62	106.60	105.27	105.73
PPDm	33.73	34.18	31.55	33.16	34.02	32.19	30.12	32.22
PPDw	18.17	17.97	15.59	16.53	17.87	15.87	14.22	16.79
PPDNCp	26.20	25.43	23.81	24.76	25.92	24.36	22.74	24.68
PYLL1 m	4.95	5.06	4.60	4.99	5.44	4.68	4.29	4.72
PYLL1w	2.46	2.54	2.12	2.41	2.71	2.15	1.83	2.29
PYLL100	4,360.96	4,436.38	3,985.16	3,985.46	3,874.38	4,586.18	4,040.81	4,181.55
PYLLC	1,058.67	1,001.67	982.93	927.37	908.76	1,096.28	997.06	1,102.35
REC	209.46	209.57	219.17	195.96	177.99	236.28	233.43	231.99
REE	17.30	13.74	14.98	13.90	12.65	17.61	17.71	15.38
REI	569.73	551.58	572.02	505.07	463.32	638.78	665.98	567.77
SMRC	101.78	96.34	96.95	95.18	95.03	102.91	99.37	106.96
SMRC1526	98.90	97.23	96.57	97.86	94.11	102.20	100.87	106.83
SMRC3039	101.43	95.30	99.03	92.00	97.37	102.36	106.43	109.80
SMRI2125	128.21	103.65	95.82	97.54	109.94	101.39	108.18	97.41
SMRI6364	84.78	119.47	102.53	121.31	72.61	125.53	120.72	112.39
SMRJ	124.81	109.87	113.74	100.61	109.39	126.34	96.00	98.68
SMRK	94.92	101.14	90.24	94.23	84.31	130.61	107.22	107.98
sum24neg	7,462.11	7,413.69	6,933.59	6,791.56	6,584.24	7,864.16	7,179.47	7,324.05

1, Paleozoic; 2, Crystalline; 3, Carbonatic Mesozoic and basal Paleogene; 4, Carbonatic-silicate Mesozoic and Paleogene; 5, Paleogene Flysch; 6, Neovolcanics; 7, Neogen; 8, Quarternary sediments; Altitude, mean value (metres about sea level); No. of inhabitants, mean value for municipality; 24neg, sum of 24 negative health indicators (LWB - SMRK)

Discussion

According to the WHO Declaration, it is the lifestyle (the way we live and work) that accounts for most of the health status of a population (about 50 %), while genetic factors and the level of health care have been attributed a portion of between 10 and 20 %. The environment, mainly its geological component, represents about a 20 % share. Therefore, we consider the differences in the health status of inhabitants, which are close to 20 % or even greater, as very significant.

Table 4 shows considerable differences in the vast majority of health indicators between individual geological units. The distinction between the most favourable and the least favourable values of health indicators,

Table 5 Environmental indicators—groundwaters, according to geological units (mean values calculated for administrative units-municipalities)

Geological unit	1	2	3	4	5	6	7	8
pH	7.18	6.98	7.53	7.47	7.50	7.16	7.25	7.24
TDS	302.27	242.70	496.12	586.79	524.64	439.73	767.13	874.19
COD_{Mn}	1.88	1.98	1.81	2.06	2.05	1.95	2.36	2.52
Ca + Mg	1.68	1.30	3.00	3.45	3.02	2.11	4.26	4.78
Li	0.007	0.006	0.010	0.018	0.020	0.013	0.031	0.025
Na	8.53	7.44	7.44	12.79	12.74	16.09	25.99	34.46
K	4.59	3.71	4.32	6.32	6.22	9.47	11.75	19.81
Ca	43.15	35.41	84.64	99.86	88.53	56.13	107.58	120.99
Mg	14.70	10.05	21.69	23.27	19.67	17.14	38.40	42.86
Sr	0.144	0.154	0.295	0.362	0.355	0.246	0.388	0.466
Fe	0.192	0.090	0.093	0.114	0.089	0.210	0.177	0.270
Mn	0.072	0.037	0.041	0.057	0.063	0.122	0.138	0.201
NH_4	0.074	0.082	0.077	0.068	0.072	0.100	0.092	0.137
F	0.11	0.09	0.10	0.12	0.11	0.11	0.17	0.17
Cl	13.18	10.27	14.21	21.24	17.14	21.66	46.57	58.50
SO_4	45.65	34.48	50.30	65.38	62.72	49.70	89.91	119.83
NO_2	0.07	0.08	0.04	0.08	0.10	0.09	0.10	0.16
NO_3	18.02	14.82	17.80	21.72	16.19	26.44	62.46	69.36
PO_4	0.10	0.09	0.09	0.10	0.05	0.37	0.33	0.37
HCO_3	138.29	107.37	285.84	323.63	287.65	191.51	355.32	386.33
SiO_2	13.72	15.95	9.61	12.34	11.26	41.72	22.98	19.17
Cr	0.00107	0.00093	0.00091	0.00090	0.00095	0.00234	0.00127	0.00157
Cu	0.00332	0.00185	0.00193	0.00256	0.00167	0.00272	0.00244	0.00351
Zn	0.12576	0.08212	0.10279	0.23097	0.13470	0.23021	0.35242	0.45639
As	0.00863	0.00256	0.00317	0.00135	0.00079	0.00241	0.00164	0.00161
Cd	0.00050	0.00119	0.00238	0.00052	0.00062	0.00127	0.00103	0.00094
Se	0.00063	0.00069	0.00069	0.00074	0.00068	0.00086	0.00130	0.00134
Pb	0.00142	0.00139	0.00142	0.00121	0.00125	0.00134	0.00146	0.00143
Hg	0.00015	0.00012	0.00015	0.00014	0.00013	0.00012	0.00012	0.00016
Ba	0.04953	0.06077	0.07130	0.09801	0.06656	0.05056	0.07867	0.09005
Al	0.03162	0.04989	0.02627	0.02122	0.02170	0.05330	0.03644	0.02596
Sb	0.00720	0.00049	0.00365	0.00034	0.00062	0.00025	0.00031	0.00028

1, Paleozoic; 2, Crystalline; 3, Carbonatic Mesozoic and basal Paleogene; 4, Carbonatic-silicate Mesozoic and Paleogene; 5, Paleogene Flysch; 6, Neovolcanics; 7, Neogen; 8, Quarternary sediments; data in mg l^{-1}, except of pH and Ca + Mg in mmol l^{-1}

in many cases, is very significant and very often exceed a level of 20 %. Age specifications and indicators of reproductive health (a group of the first eight health indicators) involved in our study are not regarded as relevant. They are noticeably influenced by the demographic situation in Slovakia, especially by moving of mainly younger people to big cities because of better job opportunities as well as by various local differences in religious and socio-economic patterns. All these indicators are fairly balanced. The only significant difference is seen in the indicator Lem. The life expectancy of men is the highest in Paleogene rock environment (68.59 years) and the lowest in the rock environment of Neogene volcanics (65.88 years). A very similar trend is also reported in the life expectancy of women (difference of 2.5 years).

Table 6 Environmental indicators—soils, according to geological units (mean values calculated for administrative units-municipalities)

Geological unit	1	2	3	4	5	6	7	8
Al[a]	7.34	7.01	5.74	5.79	5.63	6.50	5.64	5.75
As	62.25	15.56	20.36	11.44	8.93	10.13	10.64	8.30
B	96.65	53.18	72.65	81.31	68.03	46.51	63.17	62.14
Ba	473.07	507.31	355.39	376.74	369.32	428.53	383.16	392.31
Be	1.69	1.65	1.44	1.47	1.31	1.33	1.36	1.37
Bi	1.43	0.48	0.51	0.41	0.39	0.42	0.29	0.27
Ca[a]	0.81	1.15	2.13	1.34	0.77	1.11	1.27	2.10
Cd	0.62	0.47	0.64	0.51	0.78	1.22	0.34	0.35
Ce	76.63	68.50	64.22	64.35	61.69	63.54	66.85	65.14
Co	11.90	15.30	14.48	11.53	11.42	12.29	10.26	11.00
Cr	48.40	70.40	85.08	87.10	110.68	63.15	86.23	85.52
Cu	90.50	23.99	28.87	35.47	22.82	22.33	19.39	22.24
F	378.36	374.23	416.63	357.63	312.27	265.16	313.76	329.68
Fe[a]	3.21	3.00	2.68	2.65	2.52	3.23	2.56	2.66
Hg	1.66	0.27	0.25	0.47	0.20	0.20	0.11	0.08
K[a]	2.05	1.87	1.66	1.73	1.74	1.55	1.64	1.67
Mg[a]	0.74	0.92	1.25	0.89	0.67	0.67	0.73	1.01
Mn[a]	0.10	0.08	0.08	0.08	0.08	0.09	0.07	0.07
Mo	0.73	0.72	0.87	0.63	0.84	0.58	0.60	0.54
Na[a]	0.82	1.15	0.72	0.81	0.85	0.89	0.86	0.85
Ni	24.46	22.63	33.71	34.96	34.07	16.81	26.15	29.59
P[a]	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.08
Pb	80.76	36.00	41.80	28.34	24.75	40.87	24.72	21.04
Sb	46.37	3.68	6.15	3.46	1.31	1.87	3.16	0.93
Se	0.15	0.15	0.15	0.18	0.18	0.13	0.13	0.16
Sn	5.96	4.52	4.32	4.86	5.23	4.16	4.78	4.43
Sr	85.85	139.91	89.73	92.38	88.49	113.21	96.72	110.72
V	85.84	84.33	77.54	79.59	77.21	98.08	71.92	75.06
W	1.26	1.05	1.03	0.88	0.85	1.08	0.85	0.85
Zn	77.65	81.67	83.93	74.21	71.71	86.76	84.45	69.93
pH_{H20}	5.38	5.37	6.42	6.30	5.71	5.98	6.46	6.89
pH_{KCl}	4.54	4.66	5.77	5.47	4.96	5.11	5.58	6.23
Carbonates[a]	0.73	1.03	4.19	2.68	0.97	1.12	1.33	4.13

1, Paleozoic; 2, Crystalline; 3, Carbonatic Mesozoic and basal Paleogene; 4, Carbonatic-silicate Mesozoic and Paleogene; 5, Paleogene Flysch; 6, Neovolcanics; 7, Neogen; 8, Quarternary sediments

[a] Macro-elements in %, microelements in mg kg^{-1}

The health indicators analysing mortality in many different ways are of more vital importance. In a number of these health indicators, substantial differences have been observed, which may indicate the association of health and the environment. Crude mortality rate in men and women (CMm CMw) is the highest in the volcanic rock environment. On the other hand, the most favourable crude mortality values both in men and women were recorded in the Paleogene rock environment. The difference between the most favourable (Paleogene) and the least favourable (volcanic) environment, in the cases of both men and women, is about 40 %. A trend reported in the case of indirect standardized mortality ratio (SMRp, SMRm

Table 7 Selected values of environmental and health indicators in contaminated areas of the Slovak Republic

	Middle slovak neovolcanics		Upper Nitra		Slovak ore Mts.	
	Contaminated area	Noncontaminated area	Contaminated area	Noncontaminated area	Contaminated area	Noncontaminated area
Health indicators						
LEm	64.04	65.13	69.71	69.56	66.30	65.48
CMw	17.53	16.99	11.21	12.07	12.82	17.81
REC	297.59	299.52	238.53	247.94	245.00	342.39
REE	34.16	23.13	19.82	15.98	19.24	21.72
REI	1,068.29	903.61	655.01	658.91	741.95	995.74
PYLLC	1,373.94	1,334.45	917.34	964.94	1,106.99	1,449.49
SMRC	100.75	100.43	96.07	98.13	97.4	108.45
SMRK	126.09	167.27	88.54	82.71	102.64	106.12
sum24 neg	9,720.63	9,454.31	6,382.88	6,294.34	8,218.60	9,201.61
Soils						
As	11.03	7.06	32.38	16.90	96.68	13.14
Cd	3.34	0.60	0.24	0.34	0.79	0.31
Cu	35.67	19.18	19.15	17.91	139.89	22.68
Hg	0.16	0.08	0.15	0.10	3.03	0.18
Pb	91.42	29.63	37.65	29.95	118.34	26.26
Sb	2.96	1.53	1.23	0.97	76.79	2.36
Zn	134.14	78.40	88.32	72.75	89.81	74.59
Groundwaters						
As	0.00194	0.00160	0.02096	0.00194	0.01217	0.00165
Cd	0.00139	0.00286	0.00444	0.00818	0.00054	0.00205
Cu	0.00263	0.00239	0.00129	0.00169	0.00413	0.00112
Hg	0.00014	0.00012	0.00015	0.00014	0.00016	0.00013
Pb	0.00198	0.00106	0.00107	0.00193	0.00163	0.00104
Sb	0.00024	0.00021	0.00019	0.00023	0.00941	0.00048
Zn	0.17592	0.25344	0.20046	0.15462	0.12486	0.12066

24neg—sum of 24 negative health indicators (LWB–SMRK), contents of risk elements for groundwater mg l^{-1}, for soils mg kg^{-1}

and SMRw) is similar. Similarly, this value is the highest in the volcanic rock environment and the lowest in the Paleogene rock environment. The difference exceeds 10 %. In comparison with Carbonatic Mesozoic rocks, Crystalline and Paleozoic rocks show less favourable values of standardized mortality ratio.

Premature mortality values (PPDm, PPDw and PPDNCp) are relatively balanced, and no significant differences between the allocated units have been documented. Out of PYLL (Potential Years of Life Lost) health indicators, PYLL100 indicator (per 100,000 inhabitants) is considered very important. Once again, the least favourable values were recorded in the area of neovolcanics, Crystalline and Paleozoic rocks. On the contrary, the most favourable values of this indicator are typical of Paleogene rocks and Mesozoic carbonatic units. The difference between the most favourable and the least favourable geological units exceeds 20 %. It seems that the most relevant value of health indicators in relation to the environment is assigned to the indicators of relative mortality, including cardiovascular diseases (REI), malignant neoplasms (REC) and diseases of endocrine and metabolism systems (REE, especially diabetes and thyroid).

In the case of all three indicators, it is obvious that the most favourable values were observed in

Table 8 Values of environmental and health indicators for two districts of the Slovak Republic

Groundwaters			Soils			Health indicators		
	Krupina	Bardejov		Krupina	Bardejov		Krupina	Bardejov
pH	7.12	7.62	Al*	6.58	5.21	LEm	63.59	70.21
TDS	409.08	484.79	As	6.98	5.73	LEw	74.06	76.42
COD_{Mn}	2.20	1.73	B	47.37	58.80	A60+	18.26	13.89
Ca + Mg	1.80	2.75	Ba	450.79	351.28	A85+	1.13	0.79
Li	0.006	0.014	Be	1.52	1.07	BIR	11.38	13.41
Na	15.036	10.338	Bi	0.57	0.31	GFR	53.51	59.24
K	12.458	4.510	Ca*	0.98	0.51	LWB	7.44	9.55
Ca	49.303	80.753	Cd	0.45	0.61	SAR	69.60	80.23
Mg	13.951	17.978	Ce	69.63	58.78	CMm	15.37	8.95
Sr	0.208	0.297	Co	14.06	11.53	CMw	13.39	7.35
Fe	0.413	0.092	Cr	61.13	121.42	SMRp	118.86	93.15
Mn	0.135	0.049	Cu	18.46	15.41	SMRm	111.53	78.04
NH_4	0.089	0.063	F	213.29	243.44	SMRw	111.35	101.41
F	0.117	0.110	Fe*	3.51	2.09	PPDm	39.45	33.80
Cl	21.45	13.77	Hg	0.06	0.10	PPDw	16.73	16.01
SO_4	34.08	44.96	K*	1.46	1.67	PPDp	24.84	19.44
NO_2	0.03	0.03	Mg*	0.59	0.52	PYLL1 m	5.68	5.12
NO_3	28.14	14.84	Mn*	0.10	0.06	PYLL1w	1.99	2.33
PO_4	0.62	0.03	Mo	0.45	0.60	PYLL100	5601.00	3,134.00
HCO_3	173.87	282.12	Na*	0.91	1.03	PYLLC	1,125.42	805.24
SiO_2	48.79	11.30	Ni	17.44	28.49	REC	243.75	174.98
Cr	0.00219	0.00071	P*	0.06	0.06	REE	22.67	15.96
Cu	0.00287	0.00162	Pb	51.63	20.73	REI	884.73	491.97
Zn	0.22101	0.15654	Sb	1.03	0.64	SMRC	94.16	91.47
As	0.00163	0.00114	Se	0.07	0.11	SMRC1526	94.25	85.95
Cd	0.00296	0.00025	Sr	111.41	79.52	SMRC3039	94.17	81.33
Se	0.00063	0.00068	Sn	3.40	5.34	SMRI2125	105.62	102.34
Pb	0.00109	0.00094	V	113.07	64.60	SMRI6364	166.32	93.61
Hg	0.00011	0.00011	W	1.17	0.73	SMRJ	104.73	38.56
Ba	0.05145	0.06306	Zn	105.86	56.69	SMRK	119.72	53.58
Al	0.05347	0.01234	pH_{H2O}	6.06	5.61			
Sb	0.00016	0.00013	pH_{KCl}	5.21	4.69			
			Carbonate*	1.68	0.21			

Data for groundwater except pH and Ca + Mg (mmol l^{-1}) in mg l^{-1}; for soils—*macro-components in %, microcomponents in mg kg^{-1}

Paleogene Flysch. The least favourable values of these indicators are associated with environment of volcanics. Again, the differences between the most favourable and the least favourable geological units exceed 30 %.

The last group of health indicators is represented by indirect age-standardized mortality from defined causes. These indicators have been standardized to a Slovak standard, and the population was divided into 19 age groups. Mortality from malignant neoplasms of the respiratory system (SMRC3039) shows the least correlation with the geological component of the environment. The highest values of these indicators were observed in Quaternary and then Neogene rock formations. It is the most industrialized territory of the Slovak Republic, where the highest air pollution can be expected. Other rock units are mainly mountainous regions and may exhibit lower air pollution. The values of this indicator are for other geological units relatively balanced, and no significant differences between them have been documented (up to 10 %). Even in the case of the next two cancer indicators SMRC and SMRC1526, the highest values were observed in Quaternary rocks, which clearly indicate the highest degree of anthropogenic pollution (see contents of NO_3 in groundwater, Table 5). Regarding the mountainous areas, the most favourable values of these indicators were recorded for Paleogene Flysch rock environments and carbonatic strata of Mesozoic and Paleogene age, while the least favourable values were reported for volcanic rocks.

The most favourable values for infarct mortality (SMRI2125) are characteristic of carbonatic units (units 3, 4) and the least favourable, mainly for regions with Paleozoic silicates. The differences between these units are as high as 30 %. Very significant differences in geological units were observed in indicator SMRI6364 (stroke and heart attack). The most favourable values were recorded in Paleogene geological units (72.61), and the least favourable values, almost twice as high, were recorded in volcanic rocks (125.53). The largest differences between individual geological units were noticed in health indicator SMRK (mortality from diseases of the digestive system—stomach, gallbladder, liver, intestines). In the case of the most favourable geological environment, Paleogene rocks, the value of this indicator is 84.31. In case of the least favourable environment, neovolcanics, this value almost doubled to 136.61. The overall but very rough idea of the health of Slovak population is provided in a summary indicator 24neg, which represents a total of 24 negative indicators (from LBW to SMRK). Surprisingly, hand in hand with the majority of individual health indicators, the Paleogene rocks turned out to be the most favourable geological environment (6,584) and volcanic geological environment the least favourable (7,864). Based on this summary of health indicators as well as individual health indicators, the impact of the geological environment on the health of the population of the Slovak Republic can be listed in the following order of the geologic environments: Paleogene, Carbonatic-silicate Mesozoic, Carbonatic Mesozoic, Neogene, Quaternary, Crystalline, Paleozoic and volcanics (ranked from the most favourable to the least favourable).

In the Neogene and Quaternary sediments, which reflect diversified and spatially different rock material and exhibit the highest degree of anthropogenic pollution, we can see a major impact of the geological structure on the health status of the population in the older units. On one hand, mostly silicate geological units—Volcanics, Crystalline and Palaeozoic—are characterized by the least favourable values of health indicators. On the other hand, mainly carbonatic geological units—Paleogene, Carbonatic Mesozoic and Carbonatic-silicate Mesozoic—are characterized by the most favourable values of health indicators. Within the geomorphological division, rock units 1–6 represent mainly mountainous areas (note the average altitudes of municipalities across the geological units) with a largely rural population (note the average number of inhabitants in the settlements, Table 4).

The rock units of the Quaternary and Neogene are mainly lowland areas with a predominantly urban population. Higher anthropogenic contamination, particularly in groundwater (Rapant et al. 2004), is typical of these two geological units. However, a higher socio-economic level of population in these units, which could positively affect the health of population, can still be assumed. On the contrary, geological units 1–6 (mountainous areas) exhibit a relatively low degree of anthropogenic contamination with no difference in its level. Therefore, from a geological perspective, the differences in terms of health indicators discussed above can be linked to different geochemical backgrounds of given geological units but not to anthropogenic contamination.

The geogenic contamination level or geogenic-anthropogenic contamination level, especially of potentially toxic elements in Slovakia, is mainly linked with the historic mining areas. The mining mostly occurred in the geological environment of the Paleozoic and volcanic rocks, less in the Crystalline rock formations. In Fig. 2, three such mining areas are shown: Slovak Ore Mts., Middle Slovak neovolcanics (mining activities in these areas were mainly focused on Pb, Zn, Cu, Sb, Ag and Au) and the Upper Nitra region, where even now brown coal with a high content of As (up to 0.8 %) is being mined and combusted in the local power plant. In these three areas, we have designated the municipalities subject to contamination (by potentially toxic elements) and municipalities with no contamination. From a geological, geomorphological as well as socio-economic (mainly rural population) point of view, these regions are practically the same with the only difference being the contents of potentially toxic elements.

Average values of selected environmental and health indicators in these three regions (with and without contamination) are displayed in Table 7. The results are quite surprising, as we see no substantial difference in the health status of the population between the contaminated and noncontaminated regions. This phenomenon could be explained as follows: in these regions, a proportion of the potentially toxic elements being biologically accessible in soils is generally below 5 % (Rapant et al. 2009), meaning that only a small part of the potentially harmful elements pass into the food chain. The contents of the elements found in the waters of this area and posing a risk to the environment are also relatively low, due to neutral and even alkaline environments. However, in general, the similar health status of the populations is due to the fact that the contents of hazardous elements are not very high. Despite the fact that these health-risk elements get absorbed in human tissues and fluids (Rapant et al. 2006), it seems that there are some adaptation mechanisms causing certain resistance of the human body to these elements. It is likely that geochemical background (especially macro-elements) in these areas might have a decisive impact on the health of the local population.

The significant differences in health indicators of geological units discussed above can hardly be associated with different lifestyles, different level of health care or genetic factors. Slovakia is a relatively small country (with an area of less than 50, 000 km^2 and population of about 5.5 million), and no substantial differences in any of these three factors have been observed throughout Slovak regions so far. There are, of course, some distinctions between rural and urban population, especially concerning the lifestyle and also perhaps the level of health care. The ratio of the rural and urban population is, however, very similar in the geological units we have selected (see the average number of inhabitants in Table 4). The only factor, which differs markedly, is the geological bedrock that accounts for the different geochemical background of the units (Tables 5 and 6). It would be very complicated to connect the different health status of the population in the allocated geological units with potentially toxic elements (Tables 5 and 6). Their level, both in groundwaters and soils, is roughly the same.

The average content of potentially toxic elements is largely below the exposure limits for a healthy and unpolluted environment. For example, the values of As in groundwater ranges from 0.00079 mg l^{-1} (Paleogene) to 0.00863 mg l^{-1} (Crystalline), which is below the standard values for drinking water (0.01 mg l^{-1}). The contents of Hg in different units differ only within the range of 0.00012–0.00016 mg l^{-1}. The same pattern is also repeated for other potentially toxic elements. The only significant differences were evident in the case of Al with the contents in groundwater in silicate geological units (volcanics, Crystalline and Paleozoic) about twice that of carbonatic units (Paleogene, Carbonatic and Carbonatic-silicate Mesozoic). In soils, more substantial differences in the contents of potentially toxic elements in the selected geological units were observed. The highest contents of As were found in the Crystalline geological unit (62.25 mg kg^{-1}), while in other units, the contents range from 8.3 to 20.36 mg kg^{-1}. Nevertheless, in the least favourable geological unit of volcanics, the arsenic contents show relatively low values (10.13 mg kg^{-1}). A similar pattern can also be observed for Hg. The highest mercury levels are typical of the Crystalline unit (1.66 mg kg^{-1}). However, in the least favourable unit of volcanics, the mercury contents are considerably lower. No significant differences in the contents of potentially toxic elements were documented for other geological units. Thus, the contents of potentially toxic elements in soils in different geological units usually are below the threshold limits for noncontaminated environments in different geological units.

More significant differences are evident in macro-elements, particularly, in groundwater. The biggest differences between the geological units were observed in groundwater with regard to the concentrations of Ca and Mg, water hardness, total dissolved solids, Na, K and SiO_2. The contents of Ca and Mg as well as water hardness are significantly lower in the silicate geological units and highest in the carbonatic units, with an exception of the Neogene and Quaternary units exposed to the highest anthropogenic impact (see NO_3 values in Table 5). The most significant differences in macro-elements between geological units were noticed in the case of SiO_2 with the highest levels recorded in the volcanics (42.53 mg l^{-1}) and the lowest levels in the Mesozoic carbonates (8.91 mg l^{-1}). In soils, the highest contents of Ca and Mg and correspondingly the highest carbonate content values, pH_{H2O}, pH_{KCl} were in the Carbonatic Mesozoic units, while the lowest contents were in silicate the Crystalline and Paleozoic units.

The results in Table 8 offer the most convincing evidence of the impact of the geochemical background on the health status of the Slovak population. This table shows a comparison of the environmental and health indicators for two districts located in two, mostly diverse, geological units—Paleogene Flysch (Bardejov district) and Neogene volcanic rocks (Krupina district). The contents of Ca and Mg and water hardness in the Krupina district (the entire district with 36 municipalities falls into the volcanics geological unit) are noticeably lower than those in the Bardejov district (the entire district with 86 municipalities falls into the Paleogene geological unit). In contrast, alkali levels (Na and K) in the Krupina district are about twice those in the Bardejov district.

In addition, significant differences between these two districts were also observed in the values of health indicators. The average life expectancy of men is almost 7 years lower in the Krupina district than in the Bardejov district. In the Krupina district, the relative mortality from cardiovascular diseases (REI) is more than 80 % higher than that in the Bardejov district. The highest differences were observed in the SMRK indicator (mortality from digestive system diseases). The values of this indicator in the Krupina district are more than 100 % less favourable than those in the Bardejov district. Moreover, almost all health indicators show a similar pattern—unfavourable values of health indicators are typical of the Krupina district, while much more favourable values are typical of the Bardejov district.

Chemical elements in groundwater are found mainly in dissolved form, which is most available to human organism. Therefore, groundwater/drinking water tend to mostly affect the health status of the population—much more than soils.

The main objective of this work was to evaluate the health status of the Slovak population in relation to the different geological units characterized by the concentration of the chemical elements. Detailed analysis of the impact of individual elements, or a group of elements, to different types of diseases will be carried out in the future research (in collaboration with professional statisticians) using various statistical methods, especially nonlinear regression and neural networks.

Based on the results of this study, we can address two important types of diseases—cardiovascular and oncological health problems—accounting for 80 % of the deaths in the Slovak population. The incidence of both types of diseases is mainly associated with the contents of Ca and Mg in groundwater, as Ca^{2+} and $Mg^{2+}$are important intracellular cations, which are significantly involved in many enzymatic systems. They are essential for hematopoiesis, heart activity as well as in the prevention of oncological diseases (Bencko et al. 2011). We can clearly confirm that soft water significantly increases the incidence of cardiovascular diseases by more than 50 %. Our results are fully in accordance with a number of similar studies (e.g. Dawson et al. 1978; Shaper et al. 1980; Rylander et al. 1991).

Moreover, we have also documented increases in oncological diseases in the areas with low Ca and Mg contents (about 20–30 %). The epidemiological studies show that the influence of Ca and Mg on the increased occurrence of cancer is ambiguous. Some of the studies suggest an increased incidence of cancer (breast, prostate, stomach and digestive tract) at raised Ca or Mg contents in human tissues and fluids, while some report exactly the opposite results (Rodriguez et al. 2003; Larsson et al. 2006; Ahn et al. 2007; Lin et al. 2007; Butler et al. 2010).

Our results indicate an increased incidence of oncological diseases at low Ca and Mg contents in groundwater or drinking water. In addition, they are consistent with several recent studies significantly reporting on an increased incidence of cancer (pancreatic, prostate, oesophageal and breast) in connection with the deficit of Ca and Mg in drinking water (Yang 1999; Yang et al. 1999, 2000a, b, c; Chiu et al. 2004). However, in the case of oncological diseases, there is probably some favourable level of Ca and Mg in groundwater/drinking water (neither too low nor too high), which has a positive effect on the incidence of cancer. This could also be indicated by slightly less favourable values of carcinogenic health indicators (PYLLC, REC, SMRC and SMRC1526), which show slightly worse values in the geological unit of carbonates than in the Paleogene unit with a lower amount of carbonates. Purely carbonatic environments, with drinking water having high contents of Ca and Mg, were associated with an increased mortality from breast cancer (Rapant et al. 2013).

Finally, we would like to point out the major uncertainties that could affect or limit our results. Only about 20–25 % of the Slovak population has been using water from individual wells for drinking and cooking purposes (Klinda and Lieskovská 2010). About 50 % of the population has been supplied with drinking water from the local water companies using local water resources with a low discharge (less than 5 l s^{-1}) captured and distributed to water supply pipes in the vicinity of settlements, usually not more than 10 to 20 km from the same geological environment in which the municipality is located. This is particularly true for the geological units of Paleogene and volcanics, where spring discharges higher than 5 l s^{-1} are rarely found. Only in southern Slovakia (especially in the Quaternary unit), the population has been supplied from large water resources distributed distances from 50 to 100 km. Of course, we are not able to assess the proportion of different bottled water that people consume.

There are some uncertainties concerning the health indicators data as well. When a doctor reported more diagnoses as the cause of death, a registrar responsible for completing the statistical reports selected only one diagnosis—especially the one listed first (e.g. cardiovascular or renal failure). However, the selected diagnosis may not always be the main or the most fundamental cause of death (e.g. in case of an oncological patient who was treated with chemotherapeutic agents, which is usually not ranked in the first place on the list of diagnoses). The uncertainties described above could certainly modify our results. On the other hand, we have been dealing with really robust databases—a ten-year average of 30 health indicators for nearly 2,900 municipalities across the Slovak Republic, and from a geochemical point of view, we have processed more than 20,000 water samples and over 10,000 soil samples with analysis of more than 30 chemical elements as well as water and soil parameters, thus reducing the uncertainties to a great extent.

Conclusion

The results presented show that there are significant differences in the health status of the population of the Slovak Republic in relation to the diversity of the geological environment and thus the concentrations of various chemical elements. The geological environment of the Paleogene Flysch rocks (sandstones, shales, claystones) has been determined as the most favourable geologic unit for human health, while geological environment of the Neogene volcanics (andesites, basalts) as the least favourable. Overall, in terms of population health, silicate rocks—Crystalline (mainly granites, migmatites and gneisses), Paleozoic (metasediments and metavolcanics) and volcanic rocks (andesites and basalts)—are considered less favourable. On the contrary, with regard to human health, carbonatic environments are seen as the most favourable.

This study provides a good starting point for further medical and epidemiological studies focused on the impact of geological environment on population health.

After the thoroughgoing statistical analysis for environmental and health indicators (through the method of nonlinear regression and neural network), we will be able to define the elements with the highest influence on human health and derive optimal concentration ranges (minimum necessary and maximum permissible values). The present results reveal the significant effects of macro-elements (mainly Ca and Mg) on human health of residents in the Slovak Republic that seem to be much higher than the effects of potentially toxic elements. This issue is very important to be dealt with in the case of drinking water supply. Therefore, one result of our work will be recommended to water supply organizations that drinking water from the silicate rock complexes (Crystalline rocks, Paleozoic and Neogene volcanics) should be enriched with Ca and Mg.

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