Chemical composition of groundwater/drinking water and oncological disease mortality, Slovak Republic

[1]V. Cvečková, [1]K. Fajčíková, [2]B. Stehlíková, [1]S. Rapant,

[1]State Geological Institute of Dionyz Stur, Slovak Republic, veronika.cveckova@geology.sk
[2]Pan-European University, Bratislava, Slovak Republic

GEOHEALTH

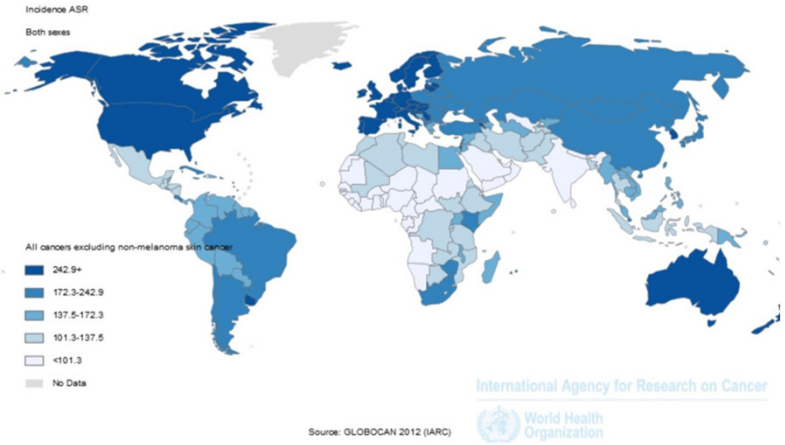
The impact of geological environment on health status of residents of the Slovak Republic.

ISEH 2016, ISEG 2016 & Geoinformatics 2016
Galway, Ireland, August 14 – 20, 2016

Onkological diseases are the second most common cause of deaths in Slovakia, about 25% of all deaths

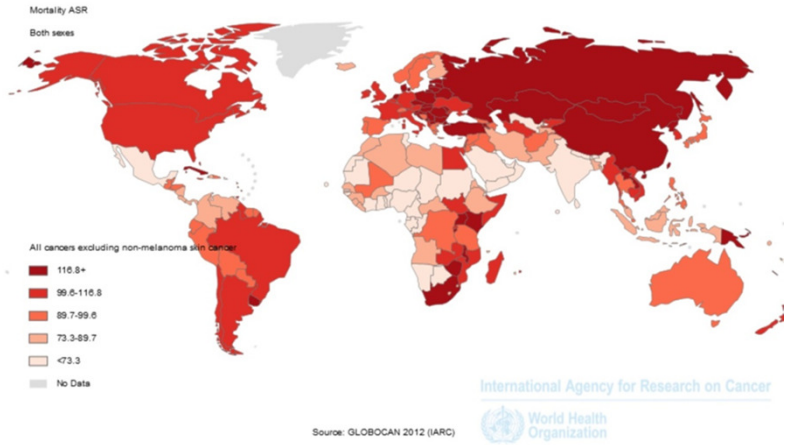
Occurrence of oncological diseases in the world

(age standardized data, Data source: GLOBOCAN, 2012)

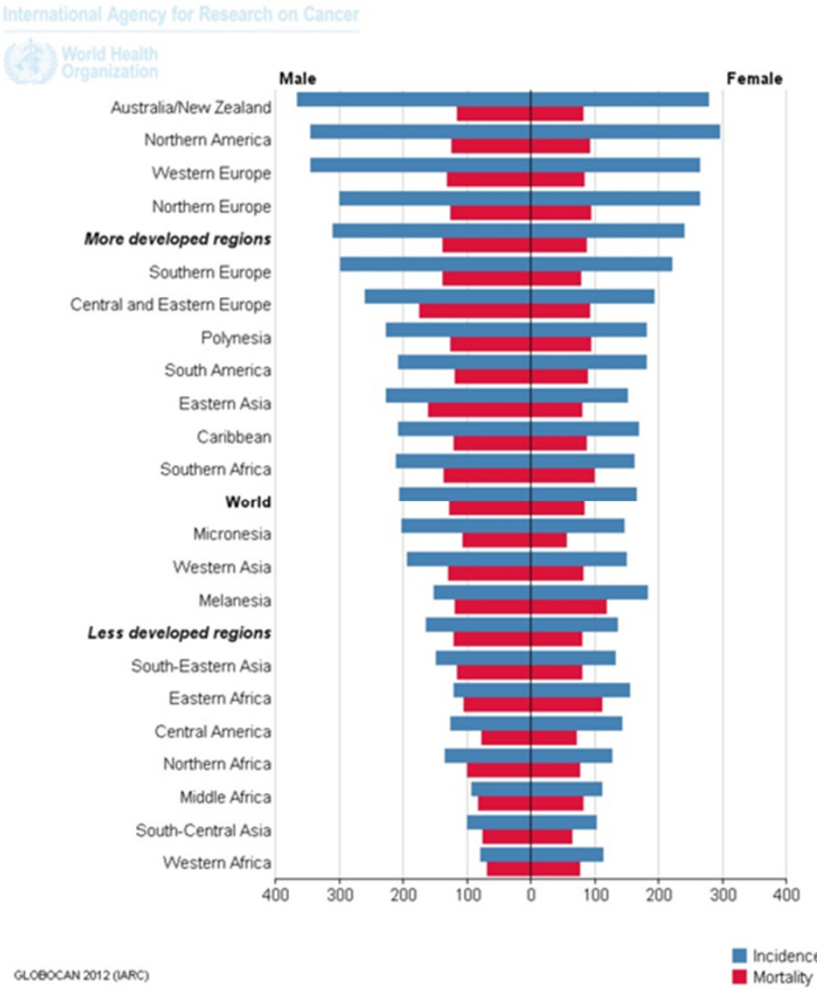


Mortality for oncological diseases

(age standardized data, Data source: GLOBOCAN, 2012)



Rate of oncological diseases for men and women in developed and less developed regions of the world (incidence/mortality, Data source: GLOBOCAN, 2012)



Objective of the work

This study deals with the analysis of relationship between chemical composition of the groundwater / drinking water and the data on mortality for oncological diseases (MOD) in the Slovak Republic

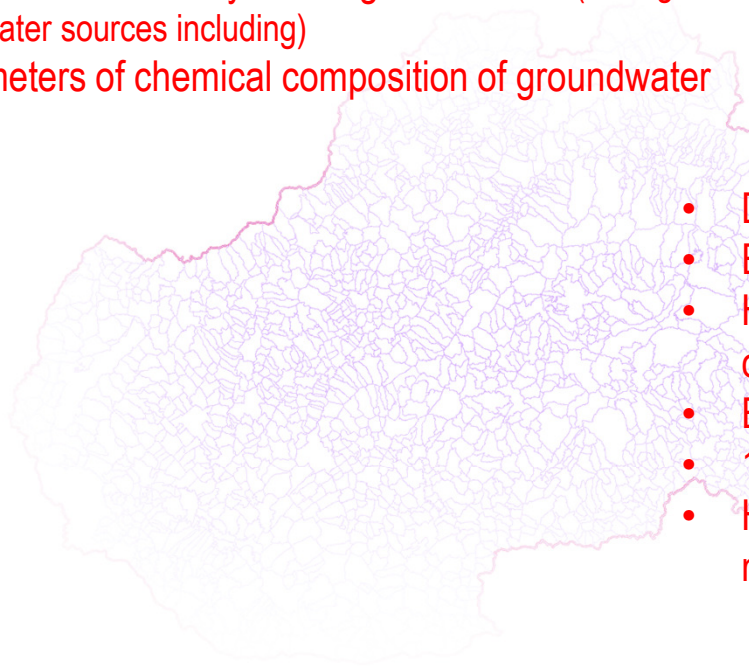
To identify the most significant chemical elements having influence on mortality for oncological diseases

To define limit values for the influential elements (maximum permissible, minimum required) at which the mortality for oncological diseases in the Slovak Republic is at the lowest levels

Materials

ENVIRONMENTAL INDICATORS represent data from:

- National geochemical database of groundwater compiled within the project
- 20 339 chemical analysis of groundwater (all significant drinking water sources including)
- 34 parameters of chemical composition of groundwater



HEALTH INDICATORS

- Data source Statistical office of the Slovak Republic
- Evaluated period 10 years (1994-2003)
- Health indicators in accordance with International classification of diseases (ICD, 10th revision)
- Elaborated through WHO recommendations
- 17 health indicators
- HI – one numerical value for each of 2,883 Slovak municipalities

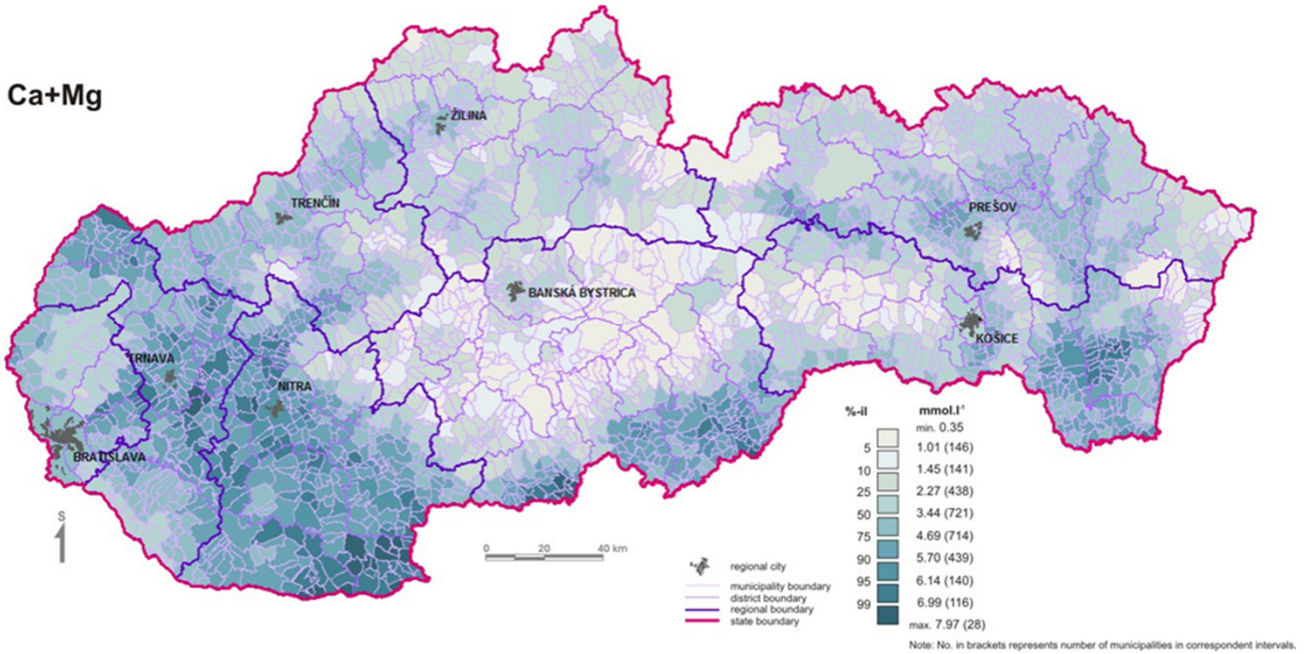
Materials

Environmental indicators (EI)

Chemical composition of groundwater (34 parameters):

pH, T.D.S., COD_{Mn}, Ca+Mg, Li, Na, K, Ca, Mg, Sr, Fe, Mn, NH_4, F, Cl, SO_4, NO_2, NO_3, PO_4, HCO_3, SiO_2, Cr, Cu, Zn, As, Cd, Se, Pb, Hg, Ba, Al, Sb, Rn^{222}, Ra^{226}

Distribution of water hardness in Slovak groundwaters- municipality level



Materials

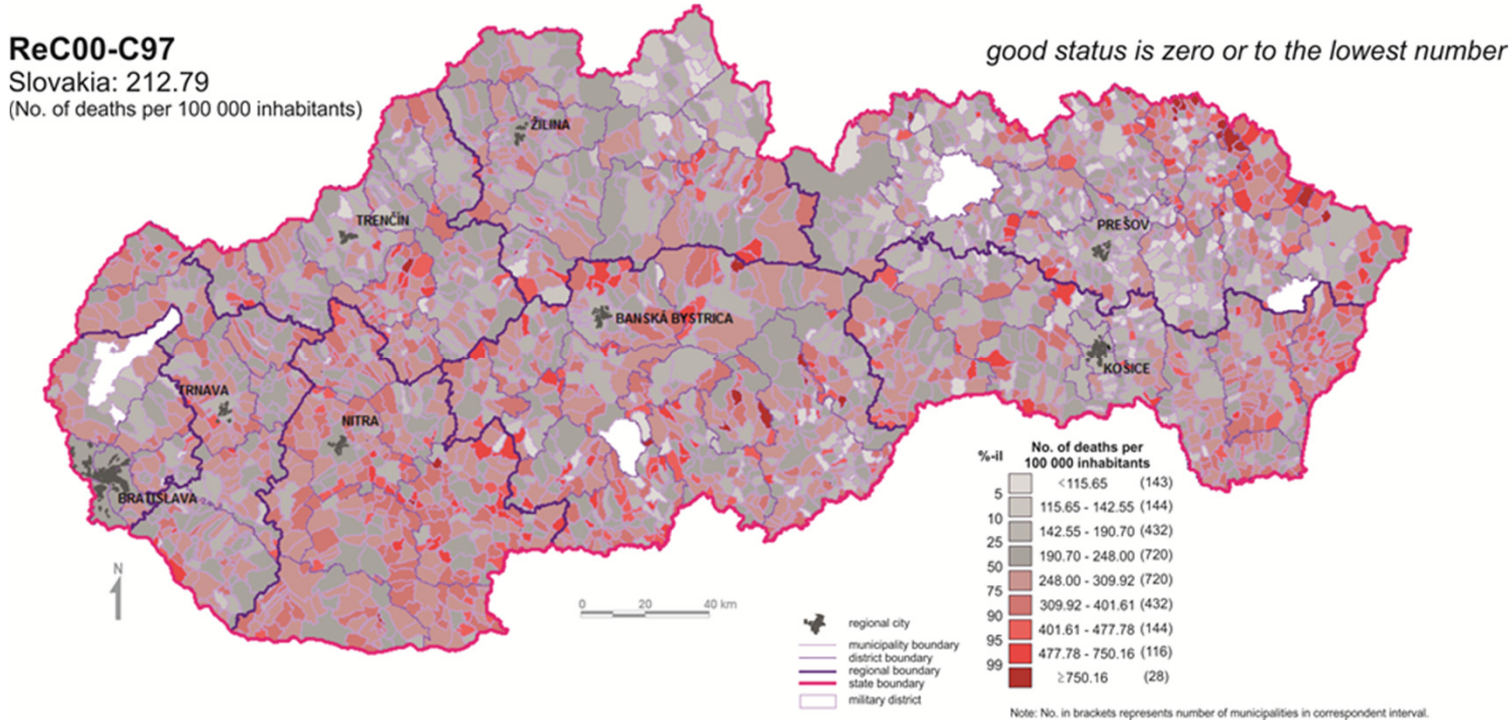
Evaluated health indicators (HI)

Health Indicator	Description of indicator	Method of calculation	Mean SR*
Relative mortality for selected cause of death			
ReC00-C97	malignant neoplasms	100 000 x [No. of deaths for selected cause / number of inhabitants]	212.79
ReC15-C26	malignant neoplasms of gastrointestinal system		76.14
ReC16	malignant neoplasms of stomach		15.2
ReC18-C20	malignant neoplasms of colon and rectum		24.24
ReC30-C39	malignant neoplasms of respiratory system		45.19
ReC50	malignant neoplasms of breast		24.8
ReC64-C68	malignant neoplasms of urinary tract		11.25
ReC81-C96	malignant neoplasms of organs of hematopoiesis		13.28
ReC91-C95	all leukemia		6.20
ReC00-D48	neoplasms (malignant, benign together)		
Standardized mortality for selected cause of death			
SMRC00-C97	malignant neoplasms	indirect age-standardized mortality rate of inhabitants to the Slovak standard (19 age groups)	100
SMRC15-C26	malignant neoplasms of gastrointestinal system		100
SMRC30-C39	malignant neoplasms of respiratory system		100
SMRC81-C96	malignant neoplasms of organs of hematopoiesis		100
Potential years of lost life for selected cause of death			
PYLLC00-C97	malignant neoplasms	100, 000 x [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]	1,005.20
PYLLC15-C26	malignant neoplasms of gastrointestinal system		242.26
PYLLC30-C39	malignant neoplasms of respiratory system		186.2

Note: Health indicators are classified according to International classification of diseases (ICD), 10th revision (http://www.who.int/classifications/icd/en/), * mean for the Slovak Republic for the period 1994 – 2003

Materials

Relative mortality for malignant neoplasms in the Slovak Republic - municipalities



Method of data elaboration

Data of environmental and health indicators are linked through following methods:

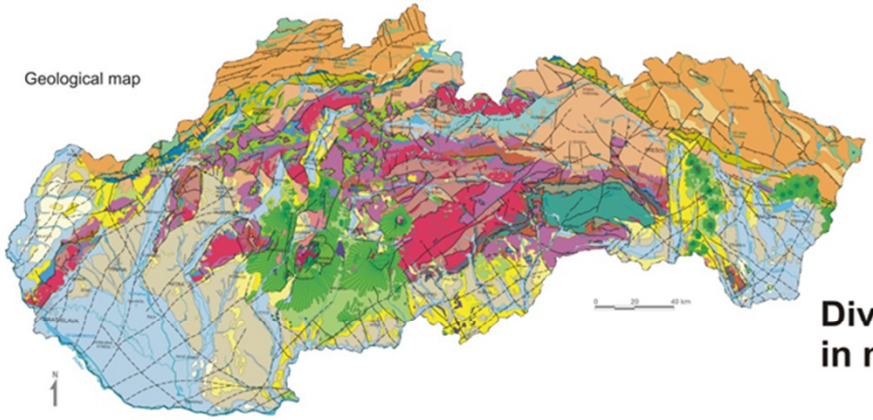
1. Comparison of health status of Slovak population according to various geological environment
2. Statistical analysis (linear Pearson and order Spearman correlations)
3. ANN – artificial neural network

Method of data elaboration

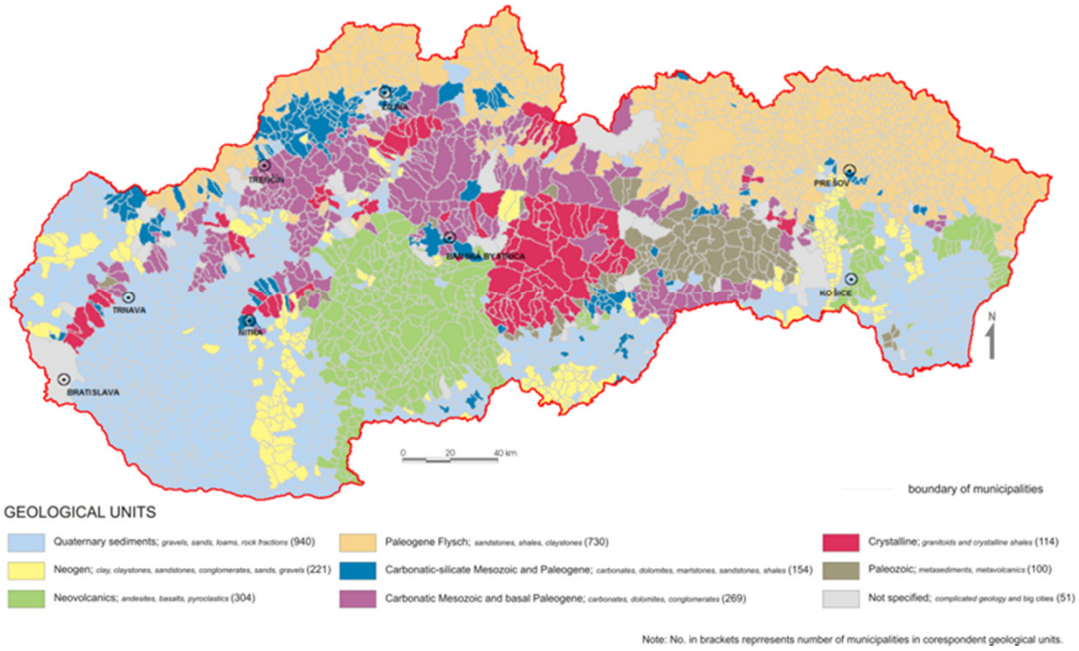
Division of geological structure of the Slovak Republic

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.



Division of geological structure of the Slovak Republic in main geological units



Note: No. in brackets represents number of municipalities in corespondent geological units.

Method of data elaboration

Correlation analysis
For selected environmental and health indicators in respective geological units
(linear and Spearman correlation coefficients)

Neural networks
Analysis of relationship between chemical composition of groundwater/drinking water and mortality for oncological diseases through

ARTIFICIAL INTELLIGENCE

ANN – ARTIFICIAL NEURAL NETWORK

Method of data elaboration

WHY WE USED Artificial Neural Network

- Our data are not normally distributed
- They are of relevance of everyday life
- They are often spoiled by errors, sometimes incomplete
- We cannot suppose the existence of linear function between them
- Use of standard regression analysis (linear and Spearman correlation coefficient) could lead to wrong conclusions
- Through ANN we are able to identify the influence of single chemical elements in groundwater / soils on health indicators
- Through ANN we are able to derive limit values (minimum necessary as well as maximum allowable) for single chemicals in relation to their influence on health indicators
- Reliability of ANN is characterized by correlation coefficient R
- Statistical significance of ANN is characterized by coefficient of determination R^2
- The level of influence of chemicals on health indicators is characterized by sensitivity coefficient (sensitivity rate) s_r, for infuential elements $s_r > 1$, for non-influential elements $s_r < 1$

- Neural networks represent one of the techniques of the data mining.
- This statistical method is rather complex, it belongs to category of artificial intelligence.
- In short –the most significant relations between environmental and health indicators are searched for.
- Each next neural network is usually of higher quality as former one because it has learned something from the created former networks, it was „trained“.
- Nevertheless, the best (correct) result is not obligatory the last trained network, that is technically the most advanced (the highest correlation coefficient).
- We use median values calculated based on 200 neural networks.

RESULTS AND DISCUSSION

Health status according to geological structure

Mean values for health indicators of oncological diseases in selected areas of the Slovak Republic

Geological unit/district	1	6	4	5	Krupina	Bardejov	SR
Health indicator	n = 100	n = 309	n = 154	n = 727	n = 36	n = 86	
ReC00-C97	209.46	236.28	195.96	177.99	243.23	175.32	212.79
ReC15-C26	72.77	85.30	71.04	62.64	95.32	61.70	76.14
ReC16	13.93	17.57	15.83	15.30	15.23	13.52	15.2
ReC18-C20	25.25	29.33	22.05	17.89	34.51	17.56	24.24
ReC30-C39	43.61	49.60	40.16	38.51	49.19	33.47	45.19
ReC50	25.75	25.67	24.80	18.62	30.58	14.27	24.8
ReC64-C68	11.31	11.62	10.73	9.60	11.53	10.79	11.25
ReC81-C96	13.34	15.46	12.60	11.71	14.66	13.70	13.28
ReC91-C95	6.20	7.69	5.87	5.23	9.11	4.69	6.2
ReC00-D48	210.48	238.21	195.68	179.24	243.23	176.63	213.62
SMRC00-C97	101.78	102.91	95.18	95.03	99.73	91.20	100
SMRC15-C26	98.90	102.20	97.86	94.11	108.40	91.56	100
SMRC30-C39	101.43	102.36	92.00	97.37	95.20	82.51	100
SMRC81-C96	103.39	107.42	97.29	98.12	91.69	111.13	100
PYLLC00-C97	1,053.42	1,097.32	921.47	909.88	1,121.60	808.81	1,005.2
PYLLC15-C26	260.15	268.13	261.11	231.28	324.48	191.11	242.26
PYLLC30-C39	191.13	217.41	169.69	170.91	268.28	143.46	186.2

1 – Paleozoic, 4 – Carbonatic-silicate Mesozoic and Paleogene, 5 – Paleogene Flysch, 6 – Neovolcanic rocks, SR – mean for the Slovak Republic, n = number of municipalities in evaluated geological unit/district

1. Significant differences exist between geological units
2. carbonatic geological units have more favourable values of oncological HI than silicate units (20-40 %)
3. Even more significant difference are documented in two compared districts (20-100 %)
4. These differences are attributed mainly to various Ca, Mg contents in groundwater/drinking water

RESULTS AND DISCUSSION

Pearson and Spearman correlation

Results of correlations between selected EI and HI

	Linear correlation			Spearman correlation		
Parameter	**r**	**P**	**significance**	**R**	**P**	**significance**
Ca & ReC00-C97	-0.082	0.001	++	-0.132	0.000	+++
Mg & ReC00-C97	-0.079	0.001	++	-0.128	0.000	+++
Ca+Mg & ReC00-C97	-0.085	0.000	+++	-0.134	0.000	+++
NO_3- & ReC00-C97	-0.050	0.043	+	-0.112	0.000	+++
As & ReC00-C97	-0.001	0.960	-	0.080	0.001	++
Pb & ReC00-C97	-0.045	0.063	-	-0.040	0.101	-
Ca & SMRC00-C97	-0.041	0.094	-	-0.043	0.082	-
Mg & SMRC00-C97	-0.013	0.603	-	-0.022	0.370	-
Ca+Mg & SMRC00-C97	-0.033	0.175	-	-0.038	0.119	-
NO_3^- & SMRC00-C97	0.012	0.618	-	-0.004	0.861	-
As & SMRC00-C97	0.006	0.798	-	0.086	0.000	+++
Pb & SMRC00-C97	-0.037	0.132	-	-0.035	0.151	-
Ca & PYLLC00-C97	-0.086	0.000	+++	-0.097	0.000	+++
Mg & PYLLC00-C97	-0.054	0.028	+	-0.081	0.001	+++
Ca+Mg & PYLLC00-C97	-0.079	0.001	++	-0.095	0.000	+++
NO_3 & PYLLC00-C97	-0.028	0.258	-	-0.042	0.086	-
As & PYLLC00-C97	-0.001	0.971	-	0.106	0.000	+++
Pb & PYLLC00-C97	-0.019	0.429	-	0.003	0.892	-

r – Pearson correlation coefficient, R – Spearman correlation coefficient, P – value; level of significance = 0.05 – verified dependence (+), P = 0.01 – high dependence (++), P = 0.001 – very high dependence (+++)

1. significant conclusions cannot be made, Our variables (EI and HI) do not have linear distribution, calculated results are not reliable
2. Correlation coefficients are very low, at level ± 0,1
3. important: R, r between Ca, Mg, Ca+Mg vs HI have negative values→ increased mortality for OD at deficit contents

RESULTS AND DISCUSSION

Artificial Neural Network

The most influential elements/parameters in groundwater in relation to health indicators of oncological diseases

element	ReC00-C97		ReC15-C26		ReC18-C20		ReC30-C39		ReC91-C95		SMRC00-C97		SMRC15-C26		PYLLC00-C97		*xP*
	s_r	P	s_r	P	s_r	P	s_r	P	s_r	P	s_r	P	s_r	P	s_r	P	
Ca+Mg	1.0269	3	1.0560	1	1.0060	3	1.1321	1	1.0863	1	1.0025	3	1.0329	1	1.0443	1	*1.8*
Ca	1.0132	4	1.0318	4	1.0079	2	1.0626	2	1.0552	2	1.0029	2	1.0248	3	1.0084	3	*2.8*
TDS	1.0740	1	1.0354	2	1.0258	1	1.0088	5	1.0133	4	1.0008	8	1.0259	2	1.0155	2	*3.1*
HCO_3	1.0338	2	1.0167	5	1.0050	4	1.0100	4	1.0037	5	1.0018	4	1.0212	4	1.0023	5	*4.1*
Mg	1.0047	8	1.0322	3	1.0011	8	1.0390	3	1.0327	3	1.0044	1	1.0205	5	1.0041	4	*4.4*
SO_4	1.0092	5	1.0065	6	1.0037	5	1.0022	7	1.0003	11	1.0006	10	1.0091	6	1.0008	10	*7.5*
Cl	1.0067	6	1.0035	7	1.0007	10	1.0027	6	1.0002	16	1.0014	5	1.0017	8	1.0016	6	*8*
NO_3	1.0064	7	1.0034	8	1.0007	11	1.0011	8	1.0003	13	1.0005	11	1.0023	7	1.0010	8	*9.1*
Na	1.0032	9	1.0016	11	1.0002	14	1.0005	10	1.0002	18	1.0004	12	1.0015	9	1.0012	7	*11.3*
SiO_2	1.0010	12	1.0019	10	1.0004	12	1.0001	20	1.0006	7	1.0009	6	1.0003	12	1.0004	13	*11.5*
Mn	1.0000	20	1.0023	9	0.9999	32	1.0000	25	1.0004	10	1.0008	7	1.0001	15	1.0010	9	*15.9*
Se	1.0014	10	1.0005	16	1.0000	22	1.0001	21	1.0002	19	1.0003	13	1.0000	28	1.0000	27	*19.5*

s_r – coefficient of sensitivity, P – order of influence, xP – arithmetic mean of order of influence for all evaluated health indicators

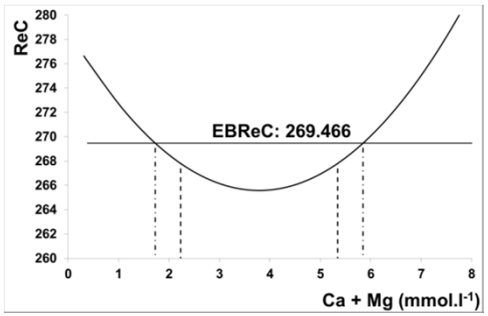
Three groups of influential elements were identified:

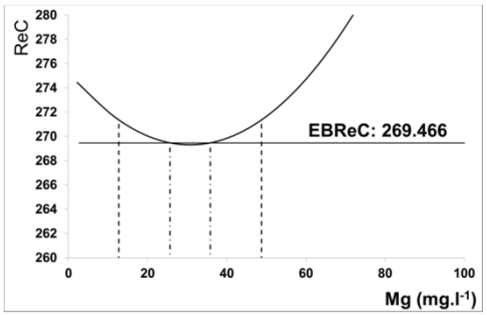
1. Ca+Mg, Ca, Mg: the most influential
2. HCO_3, T.D.S.: indicative (due to geochemical affinity)
3. SO_4, Cl, NO_3: stochastic, less influential, their increased contents are accompanied with increased Ca and Mg contents in groundwater

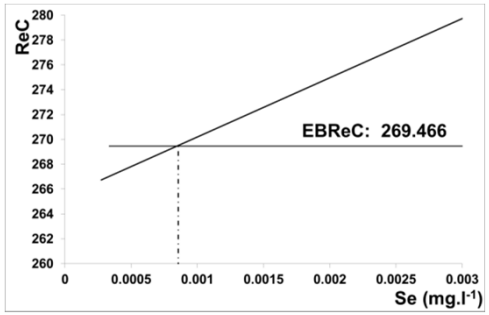
RESULTS AND DISCUSSION

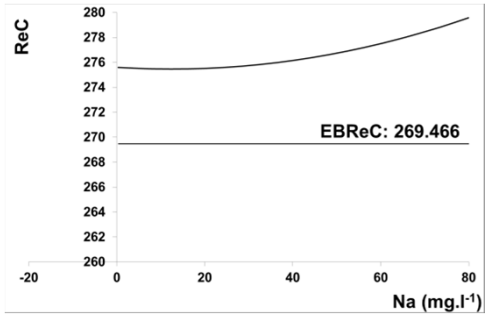
Artificial Neural Network

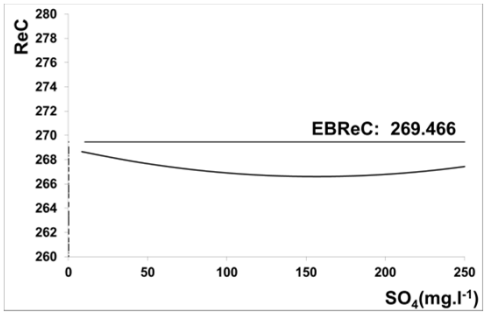
Method of derivation of limit values











Two types of limit values: limit (critical) and optimal values

Limit contents: intersection of model curve of contents of chemical elements with the mean value of HI for the Slovak Republic

Optimal contents: in case of parabola intersection of model values ± standard deviation of HI

RESULTS AND DISCUSSION

Results of calculations of ANN and derived limit values for 10 the most influential chemical elements/parameters in groundwater of the Slovak Republic in relation to ReC00-C97

Order	Parameter	s_r	R^2	Limit content		Optimal content		Evaluated function of dependence	Contents*	
				LL	UL	LL	UL		min	max
1	**TDS**	1.074	0.851	570.46	836.73	not defined	not defined	convex parabola	87.30	1412.30
2	**HCO_3**	1.034	0.850	not defined	not defined	not defined	not defined	convex parabola	16.57	592.05
3	**Ca+Mg**	1.027	0.895	1.73	5.85	2.23	5.34	convex parabola	0.35	7.97
4	**Ca**	1.013	0.987	60.56	196.84	91.18	166.21	convex parabola	9.83	201.01
5	**SO_4**	1.009	0.903	not defined	not defined	not defined	not defined	convex parabola	9.38	319.50
6	**Cl**	1.007	0.783	not defined	125.90	17.00	70.12	convex parabola	1.23	143.74
7	**NO_3**	1.006	0.582	not defined	146.58	5.50	80.24	convex parabola	1.33	227.09
8	**Mg**	1.005	0.856	25.66	35.83	not defined	not defined	convex parabola	2.45	97.75
9	**Na**	1.003	0.549	not defined	not defined	not defined	not defined	convex parabola	0.71	119.69
10	**Se**	1.001	0.978	not defined	0.0009	not defined	not defined	straight line	0.00	0.01

s_r – coefficient of sensitivity, R2 – coefficient of determination, LL – lower limit, UL – upper limit, *minimum – maximum contents of chemical elements/parameters in groundwater of the Slovak Republic (units in mg l-1, Ca+Mg in mmol l^{-1})

As non influential elements ($S_r < 1$): Pb, Zn, Cr, Sb, Hg, $_{226}$Ra, Cd, Cu, Fe, pH (practically all PTEs)

RESULTS AND DISCUSSION

Comparison of limit values of Slovak guideline for drinking water (Anon., 2010) with our derived limit values

parameter	unit	Slovak guideline limit value	Our derived limit values
Ca+Mg	**$mmol.l^{-1}$**	**1.1 – 5.0**	**1.73 – 5.85**
Ca	**$mg.l^{-1}$**	**> 30**	**60 – 196**
Mg	**$mg.l^{-1}$**	**10 – 30**	**25 – 35**

1. As influential for OD were identified only **Ca, Mg, Ca+Mg**

2. Our derived limit values are about two times higher compared to Slovak guideline for drinking water

Final limit values will be proposed after evaluation of all health indicators
(CVD, OD, GS, RS and life expextancy)

RESULTS AND DISCUSSION

Impact of other factors (except of water)

MORTALITY FOR ONCOLOGICAL DISEASES depends on series of other factors including:

- Level of contamination of other compounds of the environment (air, soils)
- Socio-economic conditions
- Rate of Gypsy population
- Level of health-care
- Lifestyle

Such data are not available for particular Slovak municipalities but are available only for selected areas and districts.

We mention them for two evaluated districts Bardejov and Krupina

Review of selected socio-economic, health-care and lifestyle characteristics for Krupina and Bardejov districts compared with the Slovak Republic

Socio-economic characteristics[a]	**Krupina**	**Bardejov**	**SR**
Level of registered unemployment (% of population)	16.95	19.6	*12.29*
Average nominal monthly salary in Euro	694	614	*957*
Rate of gypsy nationality (% of population)	2.1 - 4	4.1 - 8	*2*
Health-care characteristics[b]			
No. of physicians posts per 10,000 population - adults (age 18+ years)	4.36	3.40	*4.32*
No. of physicians 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*

[a]Statistical office of the Slovak Republic (www.statistics.sk), [b]NHIC 2013, [c]Data source for Krupina district: Kosmovský et al., 2015, [d]Data source for Bardejov district and the Slovak Republic: EHES – European Health Examination Survey (www.ehes.info), SR – Slovak Republic

RESULTS AND DISCUSSION

1. Currently, there is only case study from Taiwan performed by prof. Yang reporting the relationship between deficit Ca and Mg contents in drinking water and mortality for OD.

2. There are several epidemiological studies documenting association between increased contents of Ca and Mg in human tissues and fluids and decreased incidence of oncological diseases (Rodriguez et al. (2003), Larsson et al. (2006), Ahn et al. (2007), Lin et al. (2007), Butler et al. (2010).

3. Our results show that increased mortality for OD is observed in areas with low mineralized drinking water occurrence with deficit Ca and Mg contents or water hardness (Ca+Mg).

CONCLUSION

- ✓ Based on the achieved results we can conclude that mortality of oncological diseases in the Slovak Republic is influenced, mainly by the Ca, Mg contents and Ca+Mg levels in the groundwater/drinking water
- ✓ Increased mortality for OD is associated to low (deficit) contents of Ca, Mg and Ca+Mg
- ✓ Mortality of OD is significantly lower compared to Slovak average when groundwater content of these parameters are : for Ca > 60 mg l^{-1}, for Mg within range of 25-35 mg l^{-1} and for Ca+Mg within range of 1.7-5.8 mmol l^{-1}.
- ✓ Our derived limit values are about 2 times higher compared to limits defined within the Slovak guideline for drinking water.
- ✓ The significance of Ca and Mg groundwater contents in the Slovak Republic was also determined for mortality of cardiovascular diseases (Rapant et al. 2015). , CVD+OD=75 % causes of deaths in Slovakia
- ✓ We recommend increasing current Slovak guideline values for drinking water for Ca, Mg and Ca+Mg about 2 times

More details can be found in paper:

Rapant, S., Cvečková, V., Fajčíková, K., Dietzová, Z. & Stehlíková, B. (2016). Chemical composition of groundwater/drinking water and oncological disease mortality, Slovak Republic. Environ. Geochem. Health, in press (DOI: 10.1007/s10653-016-9820-6)

Thank you for your attention

This research has been performed within the project Geohealth (LIFE10 ENV/SK/000086)

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

Acknowledgement

Project is financially supported by the EU's funding instrument for the environment: Life+ programme and Ministry of the Environment of the Slovak Republic.

All materials are available on the project website www.geology.sk/geohealth