Slovak Geol. Mag., 12, 1 (2006), 17 – 23

Environmental and health risk assessment maps: Application of geochemical survey data

STANISLAV RAPANT

State Geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic
rapant@gssr.sk

Abstract. Through the combination of methodological approaches of risk analyses with methodological approaches of geochemical mapping, a new way of cartographic depiction and quantitative evaluation of the environmental and health risk level has been created to assess the risk from main compounds of the geological environment of the Slovak Republic. In addition to the Republic's level, the assessment of the main administrative and regional units of the Slovak Republic (districts, municipalities, catchments, and geomorphologic units) in both map and numerical form is also presented.

The calculation of environmental risk is based on comparation of PEC (Predicted Environmental Concentration) with PNEC (Predicted Non Effect Concentration) concentrations of the most significant contaminants – especially potentially toxic elements in groundwater, soils and stream sediments. Health risk – expressed either in the form of excess lifetime carcinogenic risk affections or as a chronic risk Hazard Quotient (HQ = ADD/RfD) was calculated for groundwater and soils. Performed calculations are transformed into maps on the level of total Slovak territory (areal distribution) or maps of administrative (districts, municipalities) and regional units (catchments, geomorphological units) based on the expression of the average risk for the evaluated entities.

Key words: geoenvironment contamination, potential toxic elements, environmental risk, health risk, Slovakia

1. Introduction

Since the 1980s the approach in environmental contamination assessment has been shifted from descriptive forms towards evaluation of probable adverse impacts upon other environmental compartments and human health. Terms like *environmental, ecological and health risk* have been defined and adopted and methodological procedures and legislative directives for their risk assessment have been elaborated.

Combining methods of risk analyses and results and methodological proceeding of geochemical mapping a concept of numeric evaluation and map visualization of potential environmental and health risk from contamination of geological components of the environment was elaborated. Presented work proceeds from national geochemical databases of Slovak Republic acquired within the frame of the programme of Geochemical Atlas of Slovak Republic in the scale 1 : 1 000 000 (Vrana et al., 1997) and environmental-geochemical mapping of selected regions in the scale 1 : 50 000 (Rapant et. al., 1999). In the presented work, there are summarized some examples of geochemical data elaboration and utilization at national as well as regional level (Rapant, 2002; Rapant & Kordík, 2003; Rapant et al., 2003; Rapant, 2005; Rapant & Krčmová, 2006).

2. Environmental risk

In the terms of the valid Slovak (Anon, 1998) and European (Anon, 1994) methodological approaches and directives for risk assessment and management the following definition has been adopted: Environmental risk (ER), is defined as characterizes likelihood, or occurrence possibility of adverse effects as a consequence of the environment exposure to single or several stressors. For single stressor (contaminant) it represents the ratio between its concentration within environment - Predicted environmental concentration (PEC) and concentration with presumed no negative effect upon organisms or ecological systems - Predicted non-effect concentration (PNEC). Consequently, the environmental risk can be expressed numerically by the environmental risk quotient (Q_{ER}). Its magnitude determines the occurrence probability of ill-effects of the assessed contaminant upon environment. Geochemical data, at the sufficient sampling density, in the form of PEC concentrations are representative enough for large regional scales. The best way to define PNEC value, which does not comprise the probability of environmental ill-effects, is to apply the ecotoxicological monitoring methods. The PNEC or NOAEL (No Observed Adverse Effect Level) determination of concentrations of single elements at regional scale for various types of the environment, various geological matrixes and various toxic pollutant combinations is very difficult. The regional scale is the simplest way to apply the limit concentrations from valid environmental and technical standards as PNEC concentrations. For instance in the case of groundwater there is possible to use limit values for drinking water and for soils and sediments reference "A' values of permissible indicants of contamination (so-called Dutch Lists). These values represent natural background content values valid for a non-contaminated environment. Recently, they have also been derived from

Slovak Geol. Mag., 12, 1 (2006), 17 – 23

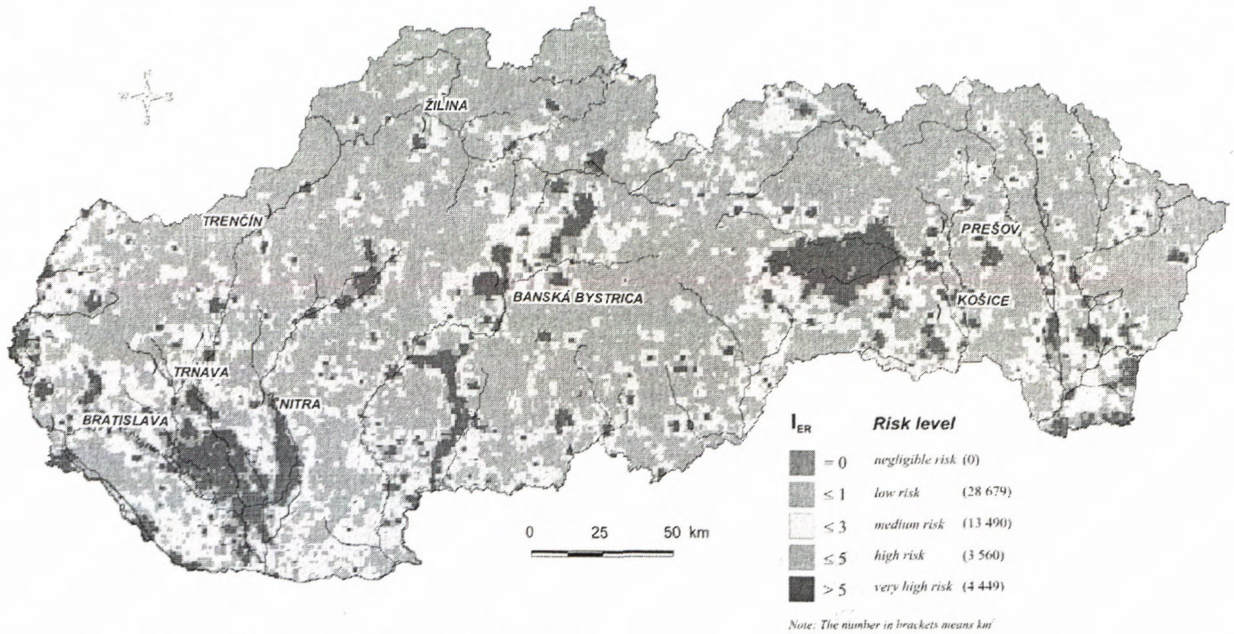


Fig. 1. Environmental risk assessment map of Slovak Republic.

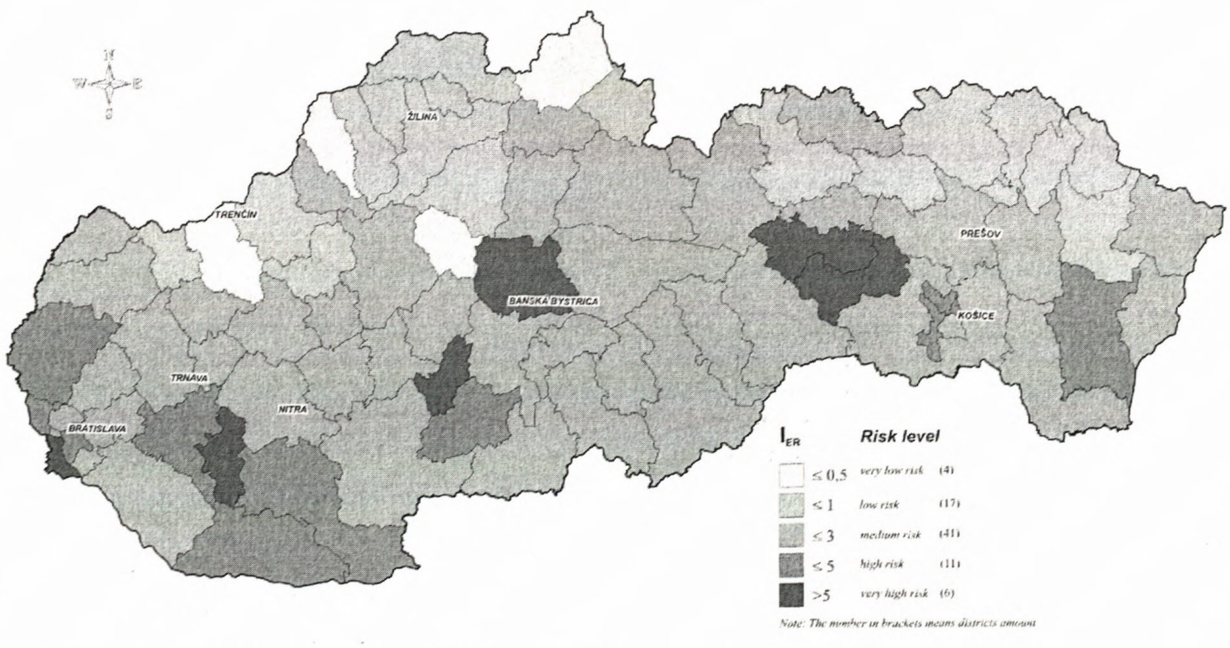


Fig. 2. Environmental risk assessment map of Slovak republic – districts.

toxicological effects of individual elements. In this case, the environmental risk quotient (Q_{ER}) represents the ratio between analytical and limit (risk) concentration values. The summary effect of several elements, in which analytical concentration values in more than one case exceed the limit values, is possible to express in form of the risk sum of individual elements by the environmental risk index (I_{ER}). Those elements, which analytical concentration levels are below their limit (risk) concentration values, have to be excluded from calculation. The environmental risk index value (I_{ER}) calculation for individual analysed water, soil and sediment samples consists of two steps. The first step is the calculation of the environmental risk quotient for each analysed chemical element/compound, which exceeds the limit risk values. In the second step, their sum is calculated according to the denoted scheme:

$$I_{ER} = \sum_{i=1}^{n} Q_{ERi} \qquad Q_{ERi} = \frac{AC_i}{RC_i} - 1$$

Q_{ERi} – environmental risk quotient of the i-element, which exceeds the risk (limit) concentration;

AC_i – i-element analytical concentration; RC_i – i-element risk (limit) concentration;

I_{ER} – environmental risk index of the sample tested.

Those contaminants, which concentration do not exceeds the limit (risk) values and, consequently they do not pose any environmental risk (ER), ought to be ignored in the calculation (their $Q_{ER} = 0$). In this way, through determination of I_{ER} for each evaluated environ-

Tab. 1. Environmental risk from contamination of geological compartments of the Slovak Republic – districts

	District	I_{ER}	I_{ERgw}	I_{ERs}	I_{ERss}		District	I_{ER}	I_{ERgw}	I_{ERs}	I_{ERss}
1	*Spišská Nová Ves*	12.81	1.41	16.60	20.41	37	*Vranov nad Topľou*	1.35	2.30	0.44	1.30
2	*Gelnica*	12.74	2.38	23.59	12.24	38	*Trnava*	1.27	2.88	0.09	0.84
3	*Šaľa*	6.18	15.08	0.20	3.25	39	*Detva*	1.25	0.57	0.48	2.70
4	*Banská Bystrica*	5.28	1.58	6.49	7.76	40	*Dolný Kubín*	1.23	0.84	1.64	1.21
5	*Banská Štiavnica*	5.22	2.96	3.16	9.55	41	*Snina*	1.18	2.02	0.47	1.05
6	*Galanta*	4.99	11.45	0.14	3.37	42	*Sobrance*	1.17	2.97	0.10	0.44
7	*Bratislava*	4.04	10.64	0.25	1.23	43	*Rimavská Sobota*	1.16	2.65	0.27	0.57
8	*Krupina*	3.49	3.58	0.70	6.18	44	*Stará Ľubovňa*	1.14	0.56	1,37	1.50
9	*Komárno*	3.43	9.06	0.11	1.12	45	*Brezno*	1.11	0,92	1.09	1.31
10	*Košice*	3.41	3.80	1.32	5.11	46	*Poltár*	1.09	2.18	0.43	0.67
11	*Michalovce*	3.16	8.14	0.38	0.95	47	*Zlaté Moravce*	1.06	1.51	0.24	1.43
12	*Nové Zámky*	3.14	6.51	0.11	2.81	48	*Revúca*	1.06	1.85	0.56	0.77
13	*Malacky*	3.12	7.72	0.28	1.37	49	*Topoľčany*	1.04	1.81	0.18	1.12
14	*Dunajská Streda*	2.92	7.39	0.06	1.30	50	*Ilava*	1.02	0.22	0.60	2.23
15	*Liptovský Mikuláš*	2.73	5.84	0.93	1.43	51	*Poprad*	1.00	1.25	0.60	1.15
16	*Žarnovica*	2.65	2.35	2.08	3.52	52	*Žilina*	0.99	1.35	0.88	0.74
17	*Prievidza*	2.63	4.85	0.60	2.45	53	*Martin*	0.87	0.69	1.10	0.82
18	*Trebišov*	2.49	6.71	0.25	0.50	54	*Humenné*	0.83	1.61	0.51	0.37
19	*Košice-okolie*	2.47	2.43	2.02	2.95	55	*Svidník*	0.78	1.20	0.45	0.69
20	*Prešov*	2.32	2.99	0.84	3.12	56	*Stropkov*	0.78	1.65	0.20	0.48
21	*Partizánske*	2.30	2.91	0.26	3.72	57	*Myjava*	0.73	0.66	0.69	0.82
22	*Hlohovec*	2.26	4.29	0.14	2.33	58	*Bardejov*	0.71	1.27	0.37	0.50
23	*Pezinok*	2.10	3.22	0.75	2.32	59	*Medzilaborce*	0.71	0.68	0.78	0.67
24	*Ružomberok*	2.07	2.81	2.61	0.78	60	*Bytča*	0.68	0.87	0.56	0.62
25	*Senec*	2.05	2.80	0.06	3.30	61	*Kežmarok*	0.66	0.54	0.75	0.68
26	*Žiar nad Hronom*	1.97	0.94	2.37	2.61	62	*Trenčín*	0.65	0.90	0.34	0.71
27	*Levice*	1.93	3.84	0.25	1.72	63	*Sabinov*	0.63	0.73	0.70	0.46
28	*Skalica*	1.92	4.32	0.11	1.33	64	*Bánovce nad Bebravou*	0.62	1.37	0.15	0.34
29	*Senica*	1.90	4.83	0.20	0.68	65	*Tvrdošín*	0.60	0.86	0.41	0.53
30	*Veľký Krtíš*	1.84	4.60	0.12	0.82	66	*Považská Bystrica*	0.56	0.73	0.57	0.38
31	*Rožňava*	1.80	0.79	1.58	3.03	67	*Čadca*	0.55	0.35	0.41	0.90
32	*Piešťany*	1.68	3.21	0.34	1.50	68	*Kysucké Nové Mesto*	0.53	0.69	0.36	0.54
33	*Nitra*	1.67	3.06	0.06	1.89	69	*Turčianske Teplice*	0.50	0.28	0.77	0.44
34	*Lučenec*	1.41	3.15	0.17	0.93	70	*Nové Mesto nad Váhom*	0.49	0.77	0.34	0.35
35	*Levoča*	1.40	1.16	1.04	2.00	71	*Námestovo*	0.48	0.42	0.14	0.87
36	*Zvolen*	1.37	1.30	0.63	2.19	72	*Púchov*	0.42	0.29	0.31	0.65

Note: I_{ERgw}, I_{ERs}, I_{ERss}, I_{ER} – environmental risk indexes for groundwater, soils, stream sediments and geological compartments as a whole.

mental sample, we will get the expression of potential cumulative risk from all contaminants, which exceed the limit risk content.

To express I_{ER} spatial distribution within individual geological components – soils, water and stream sediments – it is possible to apply mathematical-statistical approaches, which have been developed for depiction of spatial distribution of chemical elements in single-element maps in the Geochemical Atlas. These are so-called "pixel" maps – maps based on spatial distribution model, which are compiled through averaging and smoothing of primary analytical data.

Based on the above mentioned methods, the indexes of environmental risk were calculated for all samples of groundwater, soils and stream sediments, utilizing the databases of the Geochemical Atlas of Slovak Republic. Consequently, the maps of environmental risk for groundwater, soils and stream sediments were compiled.

Through the unification of the ER maps for individual geological components of the environment, the cumulative ER map from the geological environment contamination of the Slovak Republic was created (Fig. 1). This summary map was compiled in such a way that for each pixel Environmental risk indexes I_{ER} from soils, groundwater and stream sediments were summarized and averaged.

The comprehensive map provides a complex evaluation of the environmental risk resulting from contaminated geological environment. The environmental risk level was consequently transformed from the maps of whole Slovakia to the respective main regional or administrative units – geomorphological units, catchments, districts (Fig. 2) cadastral units etc. For each of the presented entities a numerical evaluation of environmental risk was also calculated (Tab. 1). Proposed method of calculation and map visualization of environmental risk level enabled to assign the areas with increased environmental risk from contamination of geological environment for the territory of Slovak Republic.

Summarizing the results we can state that more than 57 % of the territory of Slovak Republic belong

Slovak Geol. Mag., 12, 1 (2006), 17 – 23

boundary specification of contaminated regions with a sequence number

regional towns

district towns

Level of environmnemt	I_{ER}	Level of contamination	sqkm	% of Slovak territory
high	≤ 1	very low	26 000	53.0
convenient	≤ 3	low	14 000	28.5
slightly disturbed	≤ 5	medium	3 900	8.0
disturbed	≤ 25	high	4 700	9.5
highly disturbed	>25	very high	500	1

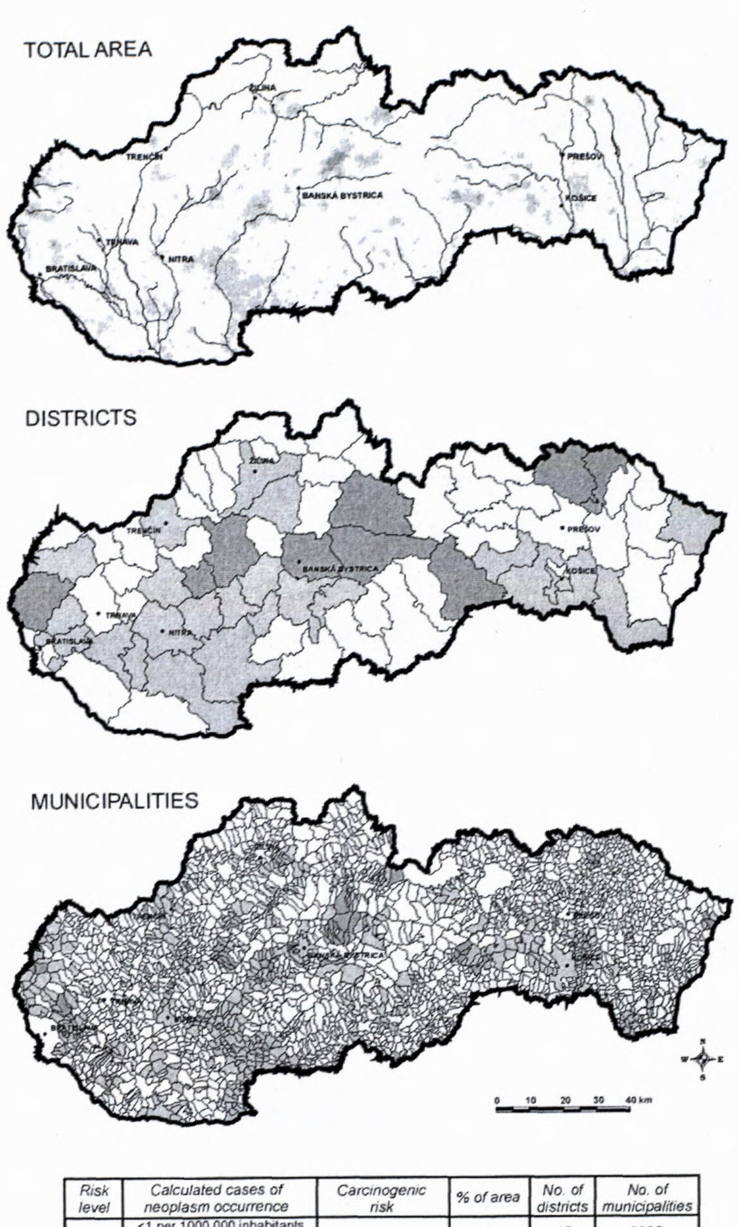
Contaminated regions:
1 Spišsko-Gemerský, **2** Mikulášsko-Breznianský, **3** Štiavnicko Krupinský, **4** Hornonitriansky, **5** Moldavský, **6** Banskobystricko-Zvolenský, **7** Bratislavsko-Senecko-Pezinský, **8** Galantsko-Sereďský, **9** Nitriansko-Šuriansky, **10** Levicko-Želiezovský, **11** Trebišovsko-Kráľovskochlmecký, **12** Juhokošický, **13** Severokošický, **14** Stupavsko-Malacký

Fig. 3. Environmental-geochemical regionalization of Slovakia.

Tab. 2. Basic characteristics of contaminated regions of Slovakia

CONTAMINATED REGIONS	*area* sqkm	I_{ER}	*THE MOST SIGNIFICANT CONTAMINANTS*			*LEVEL OF CONTAMINATION*		
			groundwater	*soils*	*stream sediments*	*ground-water*	*soils*	*stream sedi-ments*
1. Spišsko-Gemerský	910	20.7	As, Sb, Fe, Mn	Hg, Sb, As	Cu, As, Hg, Pb, Sb	++	++++	++++
2. Mikulášsko-Breznianský	650	14.5	As, Sb, SO_4	As, Sb, Cu	As, Sb, Cu, Hg	+++	++++	++++
3. Štiavnicko-Krupinský	400	9.0	Fe, Mn, SO_4, NO_3	Pb, Cu, Mo	Cd, Cu, Zn	++	+++	++++
4. Hornonitriansky	320	8.1	As, Fe, Mn, NO_3	Hg, As	As, Hg	+++	+	+++
5. Moldavský	150	20.3	Mn, NO_3, Fe	Ni, Cr, Sb, As	Sb, Ni, Cu	++	+++	++++
6. Banskobystricko-Zvo-lenský	280	13.8	Sb, Cd, As	Cu, Sb, Hg	Cu, Hg	+	+++	++++
7. Bratislavsko-Senecko-Pezinský	220	7.1	NO_3, SO_4, Fe, Mn	Ba, Sb, Cu	Sb, As, Cu, Hg	+++	+	+++
8. Galantsko-Sereďský	1 100	6.9	NO_3, SO_4, Mn, Fe	Ni, Cu	Hg, Cu, Cd, Zn, Cr	++++	+	++
9. Nitriansko-Šuriansky	290	7.0	NO_3, Mn, NH_4, Fe	Mo, Ba	Hg, Cd, Cr	++++	+	++++
10. Levicko-Želiezovský	350	4.3	NO_3, Mn, Fe	Cu, Sb, Hg	Zn, Cu, Hg	++++	+	++
11. Trebišovsko-Kráľovsko-chlmecký	1 100	4.3	NO_3, TDS, Cl, Mn	Ni, Cu, Cr	Cu, Pb, Se, Ni	++++	+	+
12. Juhokošický	150	8.2	NO_3, Mn,	Sb, As, Ni	Sb, As, Cd	++	++	++++
13. Severokošický	140	6.5	Mn, Fe, NO_3	Cu, Sb, Hg	Cu, Ba	+++	++	+
14. Stupavsko-Malacký	300	6.8	Fe, Mn, NO_3, SO_4	Hg, Ni	Hg, Sb, Zn, Cu	++++	+	++

Note: level of contamination: ++++ very high, +++ high, ++ medium, + low



Risk level	Calculated cases of neoplasm occurrence	Carcinogenic risk	% of area	No. of districts	No. of municipalities
1-3	≤1 per 1000 000 inhabitants <1 per 10 000 inhabitants	very low-medium	89.1	45	2396
4	>1 per 10 000 inhabitants <1 per 1 000 inhabitants	high	10.4	25	487
5	>1 per 1 000 inhabitants	very high	0.5	9	41

Fig. 4. Risk level maps of carcinogenic affection occurrence from arsenic groundwater contamination in Slovakia.

to category of low – negligible risk ($I_{ER}<1$). Very high environmental risk ($I_{ER}>5$) from the contamination of geological compounds of the environment occurs approximately in 9 % of the total area of Slovakia.

Based on calculations and spatial synthesis of environmental risk index [I_{ER}] distribution a territory of Slovak Republic was from the point of view of geological environment contamination (groundwater, soils and stream sediments) divided into 5 basic environment quality levels: high [53 % of Slovak territory], convenient [28.5 %], slightly disturbed [8 %], disturbed [9.5 %] and highly disturbed [1 %]. 14 the most significant contaminated regions of Slovakia were determined and characterized in areas with disturbed and highly disturbed environment (Fig. 3, Tab. 2).

3. Health risk

Potential influence of the environmental contamination by toxic elements upon the health status of the population in the Slovak Republic is manifested by calculation of the human health risk. The human health risk was calculated from soils and groundwater (potentially drinking water). The calculations were realized in two ways: US EPA methodic – calculation of lifetime chronic and carcinogenic diseases occurrence (Risk Assessment, 1999) and Hazard Quotient Calculation – HQ = ADD/RfD, The calculation supposed 70 years exposure duration, 70 kg body weight and intake by ingestion. The mean groundwater ingestion rate was estimated at 2 l per day. Soil ingestion rate for children was 100 mg/day and for adults 50 mg/day. Exposure duration (ED) for adults was 64 years and for children 6 years. Lifetime was 70 years. Exposure frequency (EF) expressed as number of days per year was in a case of soils following: for adults 40 days/years (2/7x5/12) and for children 120 days/years (5/7x6/12). As reference doses were used values defined by US EPA (1999). The results of the health risk calculations (carcinogenic and chronic effects) for individual compounds are presented in a map form.

For the carcinogenic risk level assessment (the risk of neoplasm increment) the US EPA 5-steps scale was adopted (on the base of excess lifetime cancer risk affection); (Tab. 3).

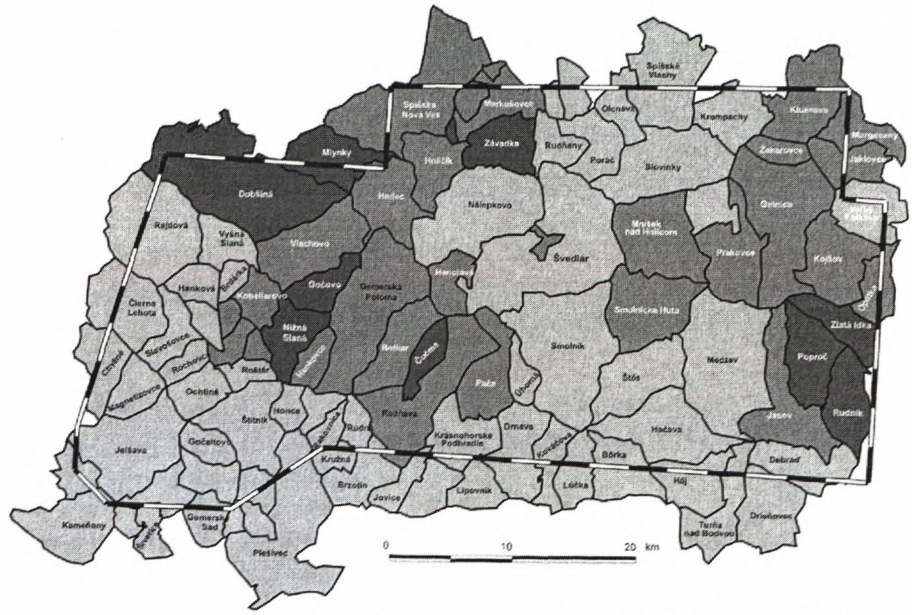
The chronic risk level was assessed also in the terms of US EPA (1999) using 4-steps assessment scale according to the ratio magnitude ADD/RfD (Tab. 4).

At the HQ of non-carcinogenic risk, the value HQ>1 is assumed as a risk presence.

From the health risk level maps – chronic and carcinogenic affections result that approximately 0.5 % of the territory of Slovak Republic is characterized with very high cancer risk (above all arsenic, Fig. 4) and 10 % of the Slovak territory comprises the areas with high risk of chronic disease occurrence from potentially toxic elements (As, Sb, Cd, Hg and Pb).

These synoptic health risk assessment maps of total Slovak territory should be considered for only orientation. For the health risk calculations it is necessary to use lower detection limits for analytical determination of chemical elements than those used compiling the geochemical atlases. Proposed methodics were successfully applied within the frame of the pilot project of medicine geology in Slovak Republic (Rapant et al., 2003), in the area of Spišsko-gemerské rudohorie Mts., which represents one of the most contaminated areas of Slovakia, mainly due to mining activities. Based on new sampling, a map of health risk assessment in relation to carcinogenic and chronic disease occurrence within particular municipalities of the region could be realized (Figs. 5 and 6).

Slovak Geol. Mag., 12, 1 (2006), 17 – 23



Calculation and carcinogenic risk level evaluation (according to the US EPA, 1998)

calculated neoplasms occurrence	carcinogenic risk level	number of municipalities
<1 per 1 000 000 inhanitants	1 - very low	0
>1 per 1 000 000 inhanitants <1 per 100 000 inhabitants	2 - low	0
>1 per 100 000 inhanitants <1 per 10 000 inhabitants	3 - medium	60
>1 per 10 000 inhanitants <1 per 1 000 inhabitants	4 - high	28
>1 per 1 000 inhanitants	5 - very high	10

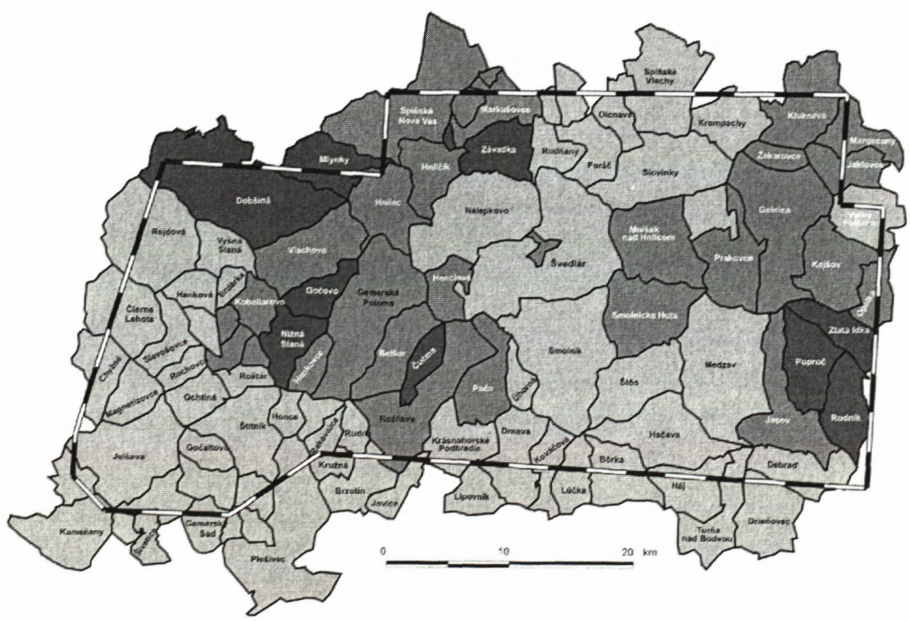
N

Štítnik name municipalities

municipalities boundary

region boundary

Fig. 5 Risk level map of carcinogenic affections from arsenic – groundwater; SGR Mts., Slovak Republic.



Calculation and carcinogenic risk level evaluation (according to the US EPA, 1998)

calculated neoplasms occurrence	carcinogenic risk level	number of municipalities
<1 per 1 000 000 inhanitants	1 - very low	0
>1 per 1 000 000 inhanitants <1 per 100 000 inhabitants	2 - low	0
>1 per 100 000 inhanitants <1 per 10 000 inhabitants	3 - medium	60
>1 per 10 000 inhanitants <1 per 1 000 inhabitants	4 - high	28
>1 per 1 000 inhanitants	5 - very high	10

Note: Symbols represent elemnts in risk

N

Štítnik name municipalities

municipalities boundary

region boundary

Fig. 6. Risk level map of chronic diseases from potentially toxic elements (As, Ba, Cd, Cr, Hg, Pb, Sb, Se, Zn) children, soils; SGR Mts., Slovak Republic.

Tab. 3 Scale for carcinogenic risk level assessment.

Risk level	*Calculated neoplasm occurrence*	*Neoplasm occurrence risk*
1	< 1 per 1 000 000 inhabitants	very low
2	> 1 per 1 000 000 inhabitants < 1 per 100 000 inhabitants	low
3	> 1 per 100 000 inhabitants < 1 per 10 000 inhabitants	medium
4	> 1 per 10 000 inhabitants < 1 per 1 000 inhabitants	high
5	> 1 per 1 000 inhabitants	very high

Tab. 4 Scale for chronic risk level assessment.

Risk level	*HQ (ADD/RfD)*	*Chronic disease occurrence risk*
1	≤ 1	no risk
2	> 1 ≤5	low
3	> 5 ≤ 10	medium
4	> 10	high

4. Conclusion

The proposed method for calculation and visualization of environmental and health risk allows to highlight those areas with enhanced risks. The new methodology for environmental and health risk calculation and visualization presented in this paper provides plenty of possibilities for the efficient application of national geochemical databases and data from geochemical atlases.

From the methodological point of view, the environmental and health risk assessment procedures can also play an important role in the calculation and visualization of environmental stress factors for geological settings.

5. References

Anon, 1994: Commission Regulation (EC) No 1488/94 of 28 June 1994 laying down the principles for the assessment of risk to man and the environment of existing substances in accordance with Council Regulation (EEC) No 793/93 (text with EEA relevance). Official Journal No L 161, 29/06/1994:0003 – 0011.

Anon, 1998: METODICKÝ POKYN MŽP SR č. 623/98-2 na postup hodnotenia a riadenia rizík.

Anon, 1999: United States Environmental Protection Agency (US EPA) – A Risk Assessment – Multiway exposure spreadsheet calculation tool.

Rapant, S., Rapošová, M., Bodiš, D., Marsina, K. & Slaninka, I., 1999: Environmental-geochemical mapping program in the Slovak Republic. Journal of Geochemical Exploration, 66 (1999), 151-158.

Rapant, S., 2002: Výpočet a mapové vyjadrenie environmentálneho rizika z kontaminácie geologického prostredia Slovenskej republiky. Zborník ref. GEOCHÉMIA 2002. ŠGÚDŠ, Bratislava, 18-23.

Rapant, S., Cicmanová, S., Mackových, D., Lučivjanská, V. & Bodiš, D., 2003: Potenciálny vplyv geochemického prostredia na zdravotný stav obyvateľstva v oblasti SGR. Záver. správa. Manuskript. ŠGÚDŠ, Bratislava.

Rapant, S. & Kordík, J., 2003: An environmental risk assessment map of the Slovak Republic: Application of data from Geochemical Atlases. Environmental Geology, Volume 44, Number 4, July. Springer-Verlag, 400-407.

Rapant, S., 2005: Proposal of the environmental-geochemical regionalization of the Slovak Republic. Mineralia Slovaca. 37/1, 1-8.

Rapant, S. & Krčmová, K., 2006: Potential health risk from arsenic groundwater contamination in Slovak Republic. Mineralia Slovaca, 38, 29-36.

Vrana, K., Rapant, S., Bodiš, D., Marsina, K., Lexa, J., Pramuka, S., Maňkovská, B., Čurlík, J., Šefčík, P., Vojtaš, J., Daniel, J. & Lučiviansky, L., 1997: *Geochemical Atlas of Slovak Republic in a scale 1 : 1 000 000.* Jurnal of Geochem. Exploration, 60, 7-37.