FINAL REPORT

The Furtherance of Internationally Acknowledged Young Researchers' Career

78876 Norwegian Fund – OTKA Project

Geochemical Transport Modelling for Contamination Risk Assessment in Sensitive Catchments

2009 – 2011

Jordán Győző

SUMMARY

The Norwegian Fund – OTKA Project (NNF 78876) 'Geochemical Transport Modelling for Contamination Risk Assessment in Sensitive Catchments' has accomplished its planned objectives. A sustainable research group of international significance has been developed and scientific research at the international level has been completed in the field of catchment-based geochemical modelling for environmental risk assessment. Two international and six Hungarian students received BSc (1), MSc (5) and PhD (2) degrees and still work for the group (PhD: 6, MSc: 1). The project has established wide national (Szeged University, Miskolc University, ELTE) and international (USGS, Baia Mare North University) research relations. Seven EU and national project proposals have been submitted based on the Norwegian Fund – OTKA Project. Besides various awards, more than 5 ISC papers and more than 20 conference presentations document the success of the project. For the 3 test sites, Recsk-Parád ore mining, Ajka red mud spill, Baiut ore mining (Romania) all field work has been completed and laboratory tests including the novel leaching tests have been accomplished. Risk assessment modelling tool has been developed and geochemical transport modelling has been initiated.

ÖSSZEFOGLALÓ

A ´Geokémiai transzport modellezés vízgyűjtők szennyezésődés kockázatvizsgálatára´ Norvég Alap – OTKA Project (NNF 78876) elérte tervezett céljait. Egy fenntartható nemzetközi jelentőségű kutatócsoport jött létre és nemzetközi szintű tudományos kutatást folytatunk a vízgyűjtő-alapú geokémiai modellezés környezeti kockázat elemzés céljából kutatási területen. Kettő külföldi és hat hazai diák kapott fokozatot BSc (1), MSc (4) and PhD (2) és dolgozik jelenleg is a csoportban (PhD: 6, MSc: 1). A projekt széles hazai (Szegedi és Miskolc Egyetemek) és nemzetközi (USGS, Baia Mare North University) kutatási együttműködést hozott létre. Hét EU és hazai projekt pályázat született a Norvég Alap – OTKA témából. A különféle díjak mellett, több mint 5 ISC publikáció és több mint 20 konferencia prezentáció dokumentálja a projekt sikerét. A 3 tanulmányterületen, Recsk-Parád ércbányászat, Ajka vörösiszap kiömlés. Baiut ércbányászat (Románia) minden terepi munkát és labor elvégeztünk, ideértve az újszerű kioldási teszteket is. Egy kockázatelemző szoftvert fejlesztettünk ki, valamint elkezdődött a geokémiai transzport modellezés.

A SUSTAINABLE INTERNATIONAL RESEARCH TEAM

In accordance with the Norwegian Fund 'The Furtherance of Internationally Acknowledged Young Researchers' Career' Programme's objective, it is proudly reported that a lively and wide international research teams has been establishment in Hungary with the help of the Fund. Based on the MAFI core group consisting of senior researcher from the Environmental Geology Department and the Laboratory Department, together with senior researchers at the Szeged University, the research team has been expanded to the Szeged University, Miskolc University and ELTE University. Also, co-operation with USGS and the Baia Mare North University, Romania has been further developed. Three international students (Leuven University Belgium, Babes-Bolyai University Romania, South Valley University Egypt) and seven Hungarian students (Miskolc University, Pécs University, Szent István University) participated in the project, with 5 PhD and 5 MSc degrees.

During project implementation, partly based on the successful project implementation, Gyozo Jordan has been appointed the Head of the Environmental Geology Department at MAFI, and received MTA Bolyai János Award and the OTKA Researcher of the Month recognition. Participating students also received various awards (including the 'Young Geologist Award, Attila Pettrik, Pécs University') and recognitions (PhD degree 'summa cum laude', Szent István University, Emőke Szlepák). Virtual research team management tools have also been installed as a part of the project, including some of the above students residing in New Zealand, Chile, Romania and in Sopron and Miskolc in Hungary, for example. Gyozo Jordan has been requested to give MSc and PhD courses on geochemical contamination assessment at the Miskolc University and ELTE University.

The activity of the project team is demonstrated by the seven EU/international (EU: Drava geochemical mapping, ThermoMap, Turkey Mine Waste Directive, plus Romanian, Chinese and Marokko Bilateral TéT proposals) and national (1 OTKA, 1 Norwegian Fund) project proposals submitted based on the Norwegian Fund – OTKA Project. This includes a new Norwegian Fund proposal in 2010. jointly developed with another Norwegian Fund project (Attila Tóth 'Interdisciplinary mapping of Drava River Valley archaeological heritage'; proposal was not approved). The team leader Gyozo Jordan has also participated on an international training course on geochemical modelling in the Netherlands.

Research results, especially those related to mine waste leaching tests for metal mobility assessment and related to the Ajka red mud spill investigations have been contributed to the international expert group work such as the ICPDR (International Commission for the Protection of the Danube River), the EuroGeoSurveys (Association of European Geological Surveys) Geochemistry Expert Group and the European Commission Inventory Expert Group for the Mine Waste Directive Implementation.

RESEARCH RESULTS

PROJECT BACKGROUND

MAFI had very serious financial difficulties in the years in 2010 and 2011 as it was indicated in previous interim progress reports. This lead to significant project delay and it required some reorganisation and re-schedule of the project. In addition, the fundamental and successful participation of the project in the national Ajka red mud mining waste environmental catastrophe investigation needed some project management considerations, too. Luckily, these changes influenced primarily publication and some numerical modelling activities at the end of project implementation. While sampling and lab analyses and tests of the Ajka red mud caused some delay

in the modelling research activities, it has brought outstanding research results of international significance.

Besides various awards, more than 5 ISC papers and more than 20 conference presentations document the success of the project. During project implementation three test sites have been established: (1) Recsk-Parád ore mining, (2) Baiut ore mining (Romania), and (3) Ajka red mud spill. The original Pecsely agricultural catchment has been replaced by the Baiut ore mining catchment in the Baia Mare mining region with trans-boundary pollution implications. An unexpected change was the inclusion of the Ajka red mud spill catastrophe area, since our Norwegian Fund geochemical mine waste leaching tests were the most advanced in Hungary, therefore our results could be directly used for the benefit of catastrophe combat.

FIELD WORK

All the planned field work has been completed, as supplemented by the unforeseen Ajka red mud spill sampling campaign. Sampling according the contamination risk assessment paradigm has been performed along the source (mine waste rock), pathway (stream sediment, stream water) and receptor (floodplain sediments and soil) for the three studied catchments of Recsk-Parád, Baiut and Ajka (Recsk-Parád has not been sampled for floodplain sediments). More than 300 samples have been collected and analysed for heavy metal content.

An outstanding achievement of the project is the high resolution geochemical mapping of the Recsk-Parád catchment that enables the identification of geochemical background, natural mineralization and anthropogenic effects. A new line in our research was the systematic drill core sampling of mining impacted agricultural floodplains in Romania in the Baiut test site. The method of sampling and sample treatment has been developed with special respect to sediment dating with OSL technology. A further exciting development of field work was the application of USGS Fast Field Test in Recsk-Parád and in Baiut that uses deionised water in a strict protocol in order to determine the leachable and therefore the mobile metal content of waste rock.

Field tests *for heavy metal mobility assessment in waste rock dumps in the Recsk-Parád and in the Baiut study areas.*

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Sample collection has been carried out along transects perpendicular to the red mud spilled Torna Creek in the Ajka catchment following the international standards of EuroGeoSurveys geochemical sampling protocols.

Field sampling according to international standards in the ***Ajka red mud spill*** *study area.*

LABORATORYANALYSES

All laboratory tests including the novel leaching tests have been accomplished. Collected solid samples (waste rock, stream sediment, floodplain sediment) were analysed for grain size and mineralogical composition by XRD at MAFI Lab. The Recsk waste rock samples the Ajka red mud samples were also studied by electron microscopy (SEM) at MAFI and at the Miskolc University. Total chemical compostion including toxic elements was determined by HF bomb, Lithium-metaborate and aqua regia extractions.

Perhaps one of the greatest achievements of the project is the testing and performing of leaching tests (MSZ, US EPA, USGS, Tessier et al. 1972 methods) and sequential extraction tests for the Recsk-Parád and Ajka red mud spill samples. The results can be used to assess the mobility of toxic elements in the mine waste and they show the dependence of lab results on the applied method.

It was a special achievement to develop and test the dissolved Fe(II)/Fe(III) lab method in consultation with USGS colleagues for the collected Baiut stream water and acid mine drainage samples.

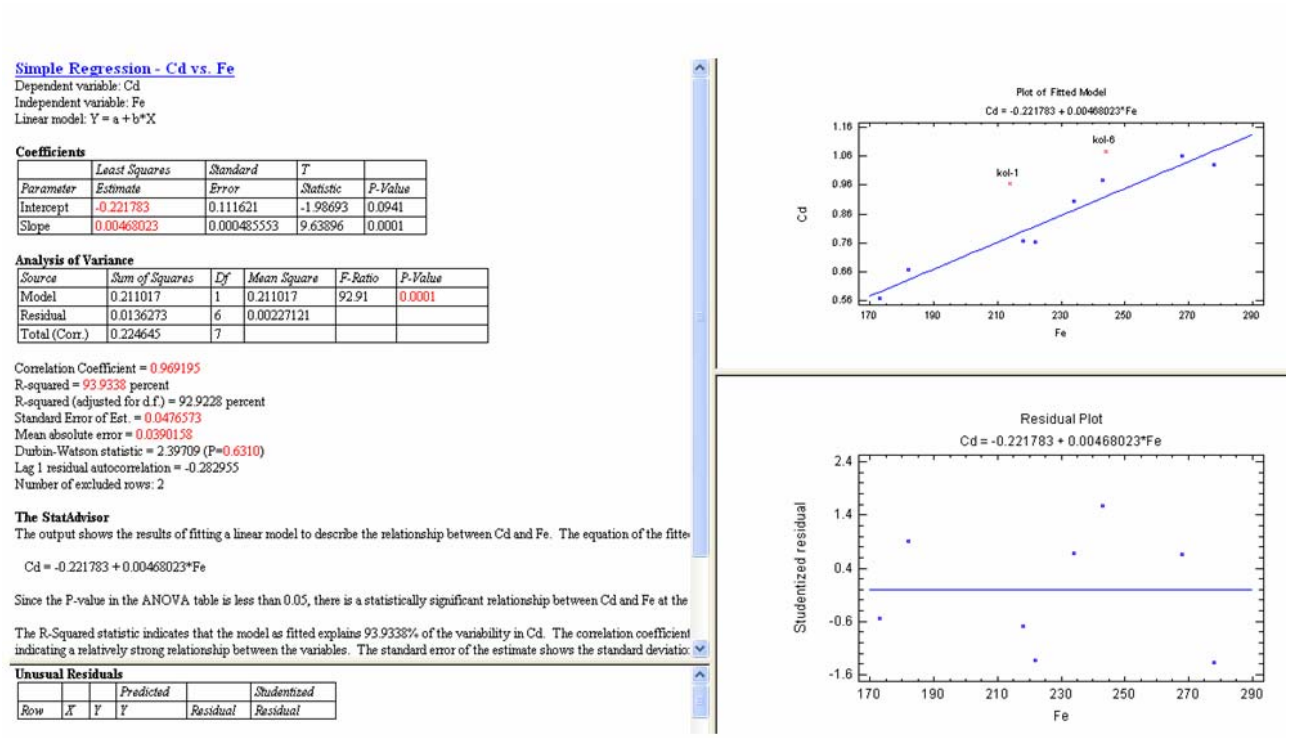
Lab leaching test *carried out by project participants in MAFI Laboratories (Dr. Andras Bartha, Head of Laboratory Department; Dr. Gyozo Jordan, Head of Environmental Geology Department; Imre Gaburi, visiting scientist).*

MODELLING

For the support of spatial transport modelling, GIS database have been developed for the Recsk and Baiut study areas, and for the Ajka red mud test site. Transport modelling has been carried out for the Recsk catchment already, although the lab analyses of collected stream sediment samples are still running and they are necessary for the final model development. Some of the analytical and modelling results are demonstrated below on the example of the Ajka red mud spill.

Elements	Method	Minimum	Lower quartile	Median	Upper quartile	Maximum	Soil MSZ (mg/Kg)	Sludge MSZ (mg/Kg)
As	deszt_viz	0.263281	1.02777	2.61614	3.36437	6.05876	15	75
	NH4_ac	0.003	0.0278609	0.0401346	0.0673531	0.107048		
	Ecet_pH8	0.0778507	0.0816653	0.0943658	0.100781	0.136542		
	Ecet_pH5	0.0831753	0.151688	0.242951	0.293096	0.607608		
	Ecet_pH3	7.47023	8.8507	10.1212	14.8454	16.1689		
Cd	deszt_viz	0.0003	0.0003	0.0003	0.0003	0.008	1	10
	NH4_ac	0.00025	0.00025	0.00025	0.00025	0.00937443		
	Ecet_pH8	0.00025	0.00025	0.00025	0.00025	0.00514704		
	Ecet_pH5	0.037746	0.0598134	0.066361	0.0760018	0.0928117		
	Ecet_pH3	0.327507	0.42298	0.524839	0.535905	0.610341		

Some resuls of leaching tests for the ***Ajka red mud*** *using various pH leachates in order to identify toxic metal mobility. Also compared to national environmental standards.*



Simple Regression - Cd vs. Fe
Dependent variable: Cd
Independent variable: Fe
Linear model: Y = a + b*X

Coefficients

	Least Squares	Standard	T	
Parameter	Estimate	Error	Statistic	P-Value
Intercept	-0.221783	0.111621	-1.98693	0.0941
Slope	0.00468023	0.000485553	9.63896	0.0001

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	0.211017	1	0.211017	92.91	0.0001
Residual	0.0136273	6	0.00227121		
Total (Corr.)	0.224645	7			

Correlation Coefficient = 0.969195
R-squared = 93.9338 percent
R-squared (adjusted for d.f.) = 92.9228 percent
Standard Error of Est. = 0.0476573
Mean absolute error = 0.0390158
Durbin-Watson statistic = 2.39709 (P=0.6310)
Lag 1 residual autocorrelation = -0.282955
Number of excluded rows: 2

The StatAdvisor
The output shows the results of fitting a linear model to describe the relationship between Cd and Fe. The equation of the fitte

Cd = -0.221783 + 0.00468023*Fe

Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between Cd and Fe at the

The R-Squared statistic indicates that the model as fitted explains 93.9338% of the variability in Cd. The correlation coefficient indicating a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviatio

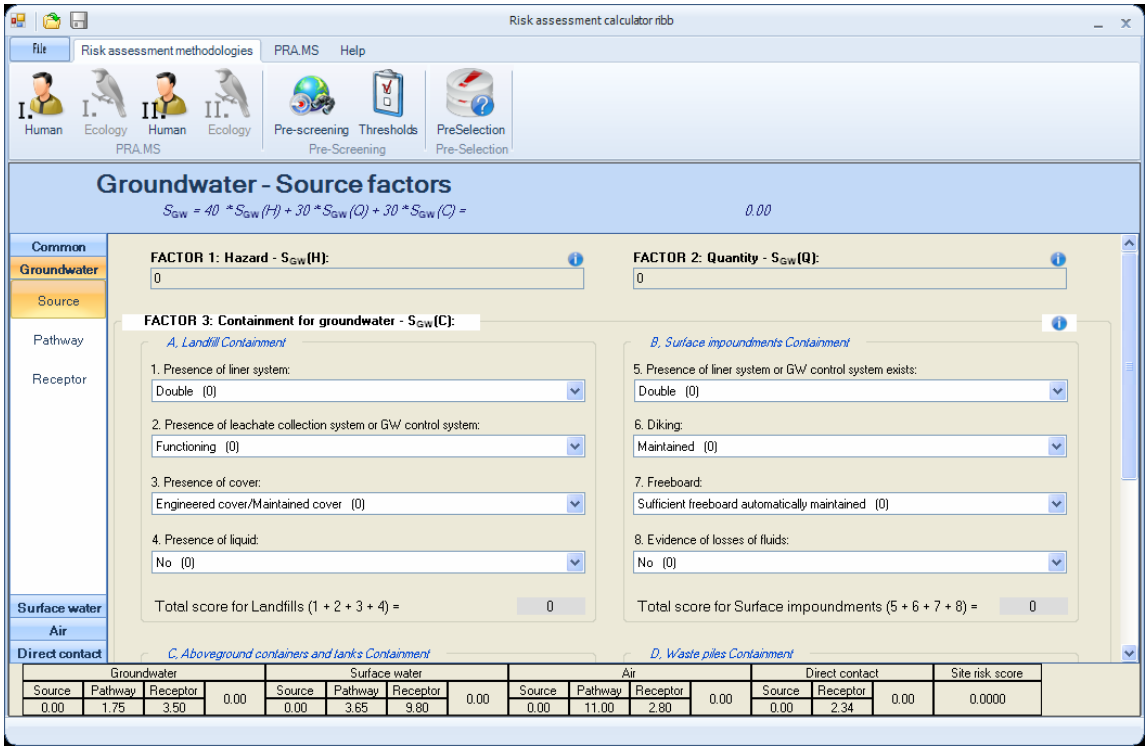
Unusual Residuals

			Predicted		Studentized
Row	X	Y	Y	Residual	Residual

Statistical geochemical modelling *results for the Ajka red mud spill. Note thestrong relationship between Fe(III) and Cd showing that Cd is specifically adsorped on the abundant iron oxide phase.*

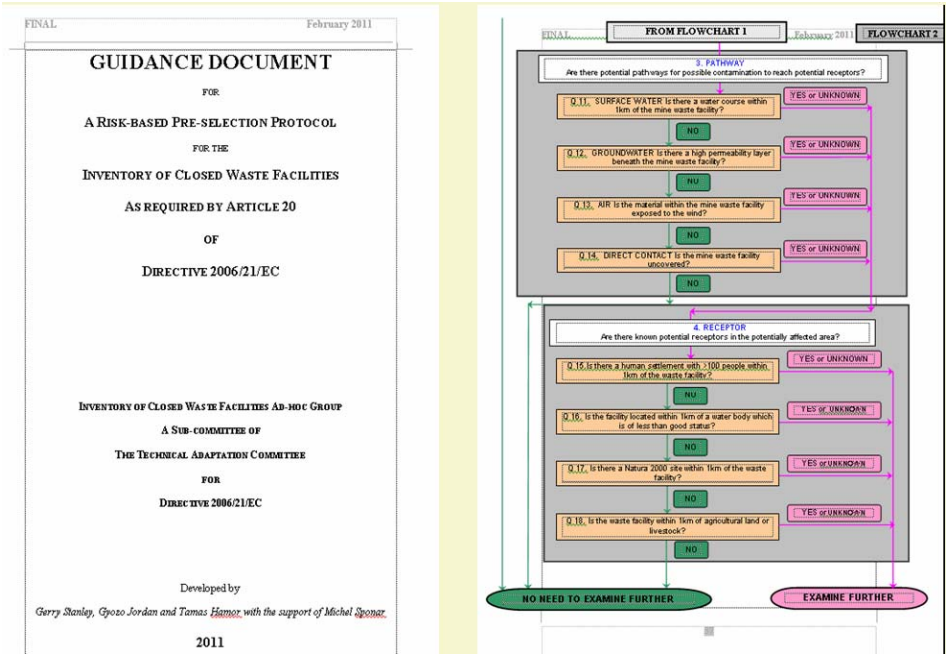
A unique result of geochemical modelling is the development and publication of the consistent **Landscape Geochemistry** method (Jordan and Szucs, 2011). This method is being tested against the Recsk-Parád and Baiut project samples and analysis results.

According to the project plan, a **risk assessment (RA) modelling tool** has been developed, primarily using the EEA PRAMS method. This enables the risk-based assessment of contamination at mine sites on a semi-quantitative basis. The developed software is able to compare various RA methods for the same site or sites, thus enabling the methodological development of RA approaches. Currently Ahmed Korany, a three-year visiting scientist from Egypt is carrying out RA with the software in combination with GIS modelling.



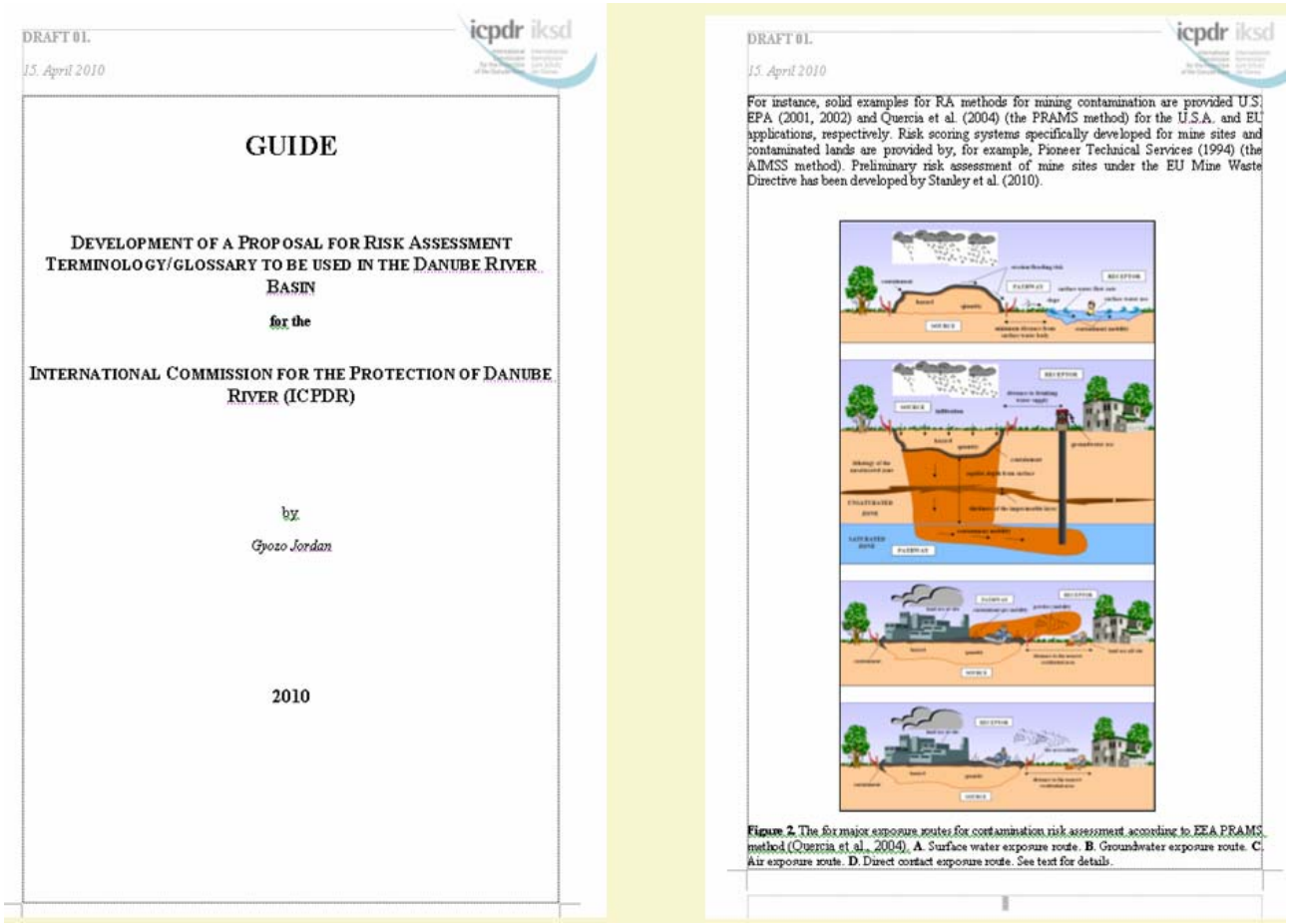
Numerical contamination risk assessment *software developed for the project. This screen shot shows PRAMS Human Health risk assessment at Tier 2, for the Groundwater exposure route Source characterisation.*

Finally, using the knowledge base generated by the Norwegian Project an EU Giudance Document has been developed: 'Gerry Stanley, ***Gyozo Jordan***, Tamas Hamor and Michel Sponar: Guidance Document for a Risk-based Pre-selection Protocol for the Inventory of Closed Waste Facilities as required by Article 20 of Directive 2006/21/EC, European Commission, 2010'.



The EU Mine Waste Inventory Guidance Document *co-authored by the project leader. The report uses the knowledge accumulated by the Norwegian Fund – OTKA Project.*

Also, project Risk Assessment results presented on ICPDR AP TG Workshops resulted in the request of development a UN ICPDR Contamination Risk Assessment Terminology Document by the project co-ordinator.



DRAFT 01.

15. April 2010

GUIDE

DEVELOPMENT OF A PROPOSAL FOR RISK ASSESSMENT TERMINOLOGY/GLOSSARY TO BE USED IN THE DANUBE RIVER BASIN

for the

INTERNATIONAL COMMISSION FOR THE PROTECTION OF DANUBE RIVER (ICPDR)

by

Gyozo Jordan

2010

DRAFT 01.

15. April 2010

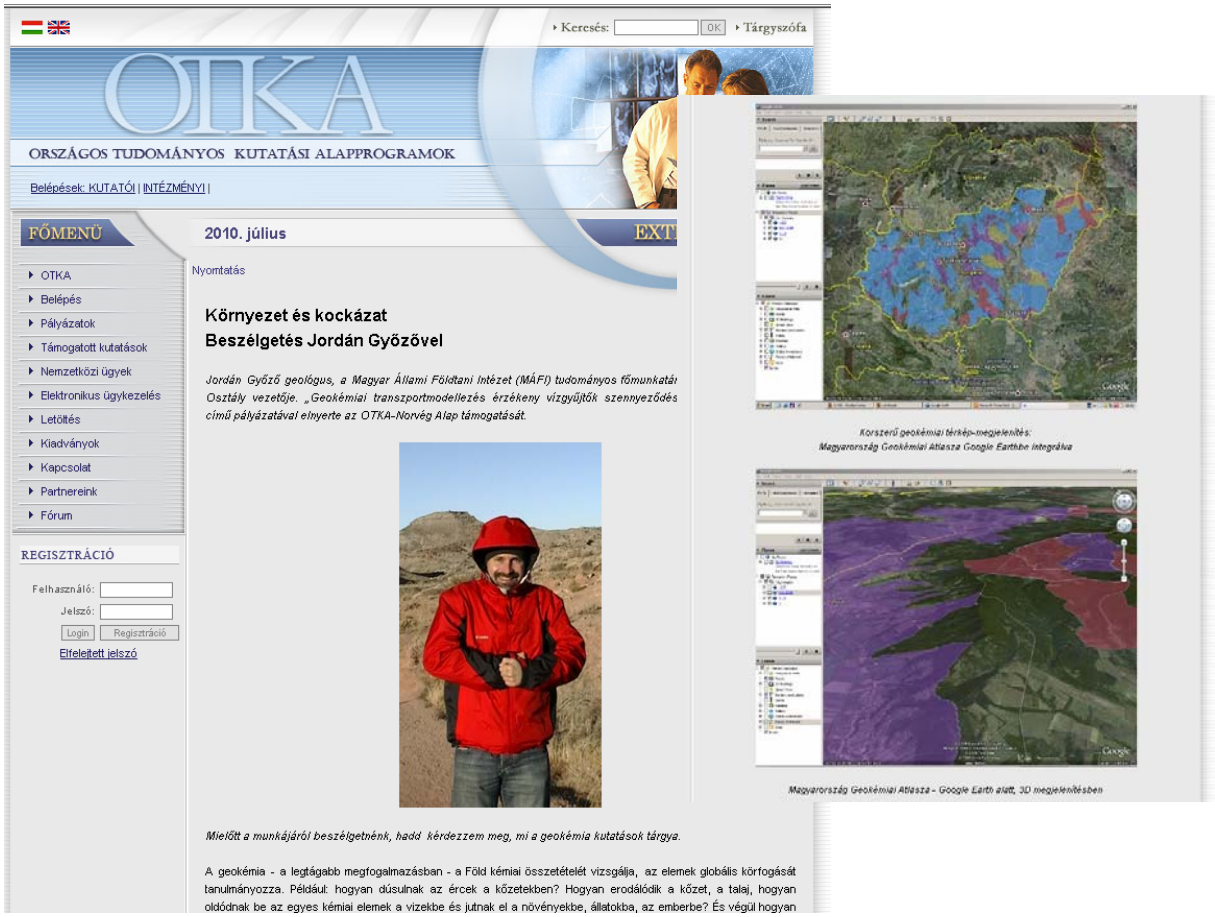
For instance, solid examples for RA methods for mining contamination are provided U.S. EPA (2001, 2002) and Quercia et al. (2004) (the PRAMS method) for the U.S.A. and EU applications, respectively. Risk scoring systems specifically developed for mine sites and contaminated lands are provided by, for example, Pioneer Technical Services (1994) (the AIMSS method). Preliminary risk assessment of mine sites under the EU Mine Waste Directive has been developed by Stanley et al. (2010).

Figure 2. The for major exposure routes for contamination risk assessment according to EEA PRAMS method (Quercia et al., 2004). **A**. Surface water exposure route. **B**. Groundwater exposure route. **C**. Air exposure route. **D**. Direct contact exposure route. See text for details.

The ICPDR Contamination Risk Assessment Terminology Document *using the results of the Norwegian Fund Project.*

OUTREACH, PUBLICITY

The Norwegian Fund – OTKA Project has been reported in an interview with Gyozo Jordan team leader under the recognition 'OTKA Researcher of the Month'. The interview summarises project approaches to geochemical modelling for environmental risk assessment.



***Researcher of the Month**, OTKA Fund (July 2010). A report with Gyozo Jordan (MAFI) on his Norwegian Fund research. Science and organisation: geochemistry for environmental decision support and the operation of an international research team.*

The results of the Norwegian Fund project were immediately used to combat the national Ajka Red Mud Catastroph ein Hungary. Research Team members were among the first in the site joining national and international scientific groups. A dedicated article has been published on the issue in the in the prestigious popular science journal National Geographic.

A report accounting for Gyozo Jordan's (MAFI) Norwegian Fund scientific research involvment in the Ajka Red Mud Catastrophe in the prestigious popular science journal ***National Geographic****.*

PUBLICATIONS

JOURNAL (ISC)

1. ***Jordan G.***, PECOMINES Project. 2009. Sustainable mineral resources management: from regional mineral resources exploration to spatial contamination risk assessment of mining. Environmental Geology, 58:153-169. (Review Paper)

2. ***Jordan G.***, A. van Rompaey, A. Somody, U. Fügedi, M. Bats, and A. Farsang, 2010. Spatial Modelling of Contamination in a Catchment Area Impacted by Mining: a Case Study for the Recsk Copper Mines, Hungary. Journal of Land Contamination and Reclamation, 17:413-421.

3. P. Szilassi, ***G. Jordan***, F. Kovacs, A. Van Rompaey and W. Van Dessel, 2010. Investigating the link between soil quality and agricultural land use change. A case study in the Lake Balaton Catchment, Hungary. Carpathian Journal of Earth and Environmental Sciences. 5: 211-223.

4. ***Jordan G.*** and Szucs A., 2011. Geochemical Landscape Analysis: Development and Application to the Risk Assessment of Acid Mine Drainage. A Case Study in Central Sweden. Landscape Research, 36:231 – 261.

OTHER ISC JOURNAL PAPER

5. Fugedi U., Kuti L., ***Jordan G.*** and Kerek B., 2010. Investigation of the hydro-geochemistry of some bottled mineral waters in Hungary. Special Issue: M. Birke A. Demetriades and B. De Vivo (Eds.) Mineral waters of Europe. Journal of Exploration Geochemistry. 107:305-316.

BOOK

1. Reimann C. and Birke M. (Eds.), 2010. Geochemistry of European Bottled Water. Borntraeger Science Publishers, Stuttgart. 268 p. Hungarian Country Team: ***G. Jordan***, U. Fugedi, L. Kuti (Geological Institute of Hungary, MAFI)

BOOK CHAPTER

1. ***Jordan G.***, Szilassi P., Van Rompaey A., Csillag G., 2009. Mit tanulhatunk a múlt területhasznosítás-változásaiból? Talajerózió és üledékszállítás numerikus környezettörténeti modellezése vízgyűjtőkben. Esettanulmány. In: Kazmer M. (editor), Környezettörténet. Az elmúlt 500 év környezeti eseményei történeti és természettudományi források tükrében. Hantken Kiadó, Budapest, pp. 223-236.

CONFERENCE PROCEEDING

1. ***Jordan G.***, van Rompaey A., Somody A., Fugedi U. 2009. Contamination transport modelling in a mining-impacted catchment. A case study for the Recsk Copper Mines, Hungary. International Conference on Applied Environmental Geochemistry - anthropogenic impact on the human environment in the SE Europe, 2009 October, Ljubljana. Proceedings, p. 66.

CONFERENCE ABSTRACT

Jordan G., van Rompaey A., Somody A., Fugedi U., Bats M., Farsang A. 2009. Spatial modelling of contamination in a catchment area impacted by mining: a case study for the Recsk Copper Mines, Hungary. International Conference on Contaminated Sites, 2009 June, Bratislava, Abstracts.

Horvath E.,Jordan G., Fugedi U., Bartha A., Kuti L., Heltai G., Kalmar J., Waldmann I., Napradean I., Damian G. 2009. Risk assessment of heavy metals in abandoned mine lands. A case dtudy in Romania. International Conference on Contaminated Sites, 2009 June, Bratislava, Abstracts. (poster)

Horvath E.,Jordan G., Fugedi U., Bartha A., Kuti L., Heltai G., Kalmar J., Waldmann I., Napradean I., Damian G. 2009. Risk assessment of heavy metals in abandoned mine lands as a signifcant contamination problem in Romania. EGU General Assembly 2009, Geophysical Research Abstracts, Vol. 11.(poster)

Horvath E., Jordan G., Fugedi U., Bartha A., Ballok M., Kuti L., Heltai G., Kalmar J., Valdman I., Napradean I and Damian G. 2009. Risk assessment of heavy metals in abandoned mine lands as significant contamination problem in Romania, Colloquium Spectroscopicum Internationale XXXVI (CSI XXXVI), 2009 August, Budapest, Abstracts. (poster)

Fugedi U., Jordan G. 2009. Cadmium contamination around mine waste sites. The regional cadmium load. Environmental MTA Geochemistry of Cadmium Workshop, 2009. May, Budapest, Abstracts (oral)

Csorba A. and Jordan G., 2010. Preliminary Results of Airborne and Ground-Based Hyperspectral Mineral Mapping of Acidic Mine Waste in the Recsk Mining Area, Hungary. Contributii Stiintifice in Tehnologii si Echimpamente Pentru Evaluarea si Protectia Mediului. Simpozium National, Arcalia (Bistrita-Nasaud), September 24 - 26, Caiet de rezumate, 33 - 34 pp. (oral, INT)

Horvath E., Jordan G., Fügedi U., Bartha A., Kuti L., Kalmár J., Valdman I., Napradean I., Damian G., Heltai G., 2010. Bányászati eredetű szennyezések vizsgálata erdélyi esettanulmány alapján, Vegyészkonferencia és 53. Magyar Spektrokémiai Vándorgyűlés, 2010. június 30 - július 2., Hajdúszoboszló, konferencia előadás, absztrakt kötet 77. oldal

Jordan G., Chira I., Dorotan D. 2010., Risk assessment of heavy metals in abandoned mines. A case study in Baiut, Romania. 12th Mining, Metallurgy and Geology Conference ,2010 April 8-11, Aiud, Romania.

PRESENTATION (invited speaker, workshop)

1. EuroGeoSurveys Geochemistry Expert Group Meeting, Belgrade, Serbia, 24-25 September 2009. (oral) (Jordan G.)

2. International Conference on Applied Environmental Geochemistry - anthropogenic impact on the human environment in the SE Europe, 2009 October, Ljubljana. (oral) (Jordan G.)

3. International Conference on Contaminated Sites, 2009 June, Bratislava. (oral) (Jordan G.)

4. International Conference on Contaminated Sites, 2009 June, Bratislava. (poster) (Jordan G.)

5. EGU General Assembly 2009 May, Vienna. (poster) (Horvath E., PhD student)

6. Colloquium Spectroscopicum Internationale XXXVI (CSI XXXVI), 2009 August, Budapest. (poster) (Horvath E., PhD student)

7. Environmental Geochemistry of Cadmium Workshop, 2009. May, Budapest. (oral) (Fugedi U.)

8. European Union/European Commission 'Working Group on Inventories' Workshop, Implementation of EU Mine Waste Directive, Budapest, Hungary, 11-13 May. (oral) (Jordan G.)

9. Workshop on Environmental Contamination in Hungary: an EU Perspective, Ministry of Environment, Budapest, Hungary, 27 March 2009. (oral) (Jordan G.)

10. Workshop on Current Issues of Environmental Site Remediation, Hungarian Chamber of Engineering, Budapest, Hungary, 22-23 April 2009. (oral) (Somody A., Zabrak Ltd.)

11. Meeting for the Geochemical Mapping of the Trans-boundary Drava Floodplain, Varazdin, Croatia, 6-8 May 2009. (oral) (Jordan G.)

12. Workshop on Co-operation for the Prevention and Remediation of Environmental Contamination, Budapest, Hungary, 18 May 2009. (oral) (Jordan G.)