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Faglig notat

New environmental impact assessment (EIA) tools of heavy metals in acid mine drainage (AMD) waters under development in Norwegian – South African research cooperation

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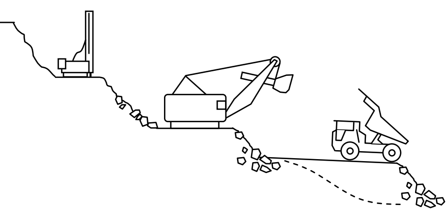
The purpose of the Witwater Project is to improve chemical and biological environmental impact assessment (EIA) tools for toxic heavy metals in AMD (Acid Mine Drainage) water from mines and mining operations with the Witwatersrand Central Basin region of South Africa as a test site.



1. BACKGROUND

1.1 The Witwater Project

The Witwatersrand Central Basin Mine Water Apportionment Pilot Study (Witwater Project) is a research cooperation project between Norwegian Institute of Water Research (NIVA), Council of Geoscience (CGS) in Pretoria, and University of Johannesburg with funds from the Research Council of Norway (RCN) and the National Research Foundation (NRF) of South Africa under the RCN South Africa II programme (2007-2011).

1.2 The Witwatersrand region in South Africa

The Witwatersrand area between Pretoria and Johannesburg in the Gauteng province has been a heavily mined area during the last 150 years (http://en.wikipedia.org/wiki/Witwatersrand_Basin). Many on-going as well as abandoned mines have high ingress of groundwater and thereby risk for overflow forming discharges of AMD water. The mine water has to be pumped and treated to reduce environmental effects in recipients. The relatively large amounts of AMD water produced has been an economical and environmental problem for authorities, regulators and mine companies, and has caused considerable public and environmental concern. In this project we wanted to examine new environmental analytical chemical and biological monitoring methods to improve environmental impact assessment (EIA) tools for management of AMD waters. The Witwatersrand region is located on the SA highland plateau. Most mines goes vertical down to depths of hundreds to over thousand metres. The ground water table is typically at 10-30 metres and the water has to be continuously pumped to prevent mine flooding. AMD water pumped from mines, discharges from tailing dumps, collection dams, trenches and ponds, as well as from mining operations, poses serious environmental problems in aquatic recipients exposing groundwater, potable and irrigation water due to high level of trace metals.

1.3 Groundwater ingress to mines and tailing runoff forms AMD water

Oxidation of sulphide minerals exposed to air and water generate sulphuric acid. This production of AMD is especially strong in tailings from pyrite ores (such as iron sulphides). Many other mined ores also bear considerable amounts of sulphides, so AMD is often a general problem related to mining. AMD waters are usually very acidic with pHs down to 2 with high levels of both major elements (sulphur, iron, manganese, aluminum, calcium, magnesium, etc) and a number of toxic trace metals (often also called heavy metals) released from the mined ores (zinc, copper, nickel, cadmium, chromium, lead, uranium etc). AMD water may contain levels of trace metal several orders of magnitude above critical toxicity effect thresholds of aquatic organisms, and undiluted AMD may be extremely toxic. In aquatic recipients AMD water becomes diluted, some metal precipitates out and some metals are removed from the watersheds by later sedimentation. Large areas of lakes and rivers may be affected, until concentration finally falls below toxicity threshold levels. The high content of trace metals is toxic for organisms in aquatic ecosystems and makes water unsuitable also for other important purposes. The quality of AMD waters are often rapidly changing. The management of this water is a serious challenge, remediation costs are high, and calls for improved methods and tools for characterization of the effluent water, for choosing appropriate abatement actions, and for evaluation of their success in the recipient.

Mine tailing dump with runoff through a collection trench	Discharge with brown iron precipitate	Affected river	Iron/manganese "year rings" at the river bead
			

Figure 1. AMD water forming precipitates of iron and manganese in river recipients. The picture to the right shows a precipitation nodule "year ring" patterns in red/brown (iron oxide) and black (manganese oxide) formed during flood/draught periods.

2. METHODS

2.1 DGT passive samplers –describe toxic fractions of metals in water

DGT (Diffusive Gradient in Thin films, www.dgtresearch.com) is a passive sampler with very useful properties for collection and determination of bioavailable fractions of metals in water. It was developed during the 1990thies (see Davison and Zhang (1994) and Davison et al. (2000)). DGTs have been further developed at NIVA (Garmo et al. 2003), and is now a general tool used for metal speciation and fractionation (Figure 2). The DGTs collect the soluble bio-available and toxic fractions of trace metal ions by diffusion processes similar to uptake over cellular membranes in organisms. DGT collect time weighted average (TWA) values, i.e. an expression of dose versus time similar to a dosimeter, which is very useful in toxicological evaluations (Røyset et al. 2005). This gives DGTs high potential to predict toxic effects for response indicator organisms in the recipient such as benthic invertebrates, which often are used as indicators of AMD effects on aquatic recipients. The AMD water chemistry is often rapidly changing by floods/draughts or fluctuating discharges, and are difficult to monitor by conventional water sampling which mainly provide snapshots.

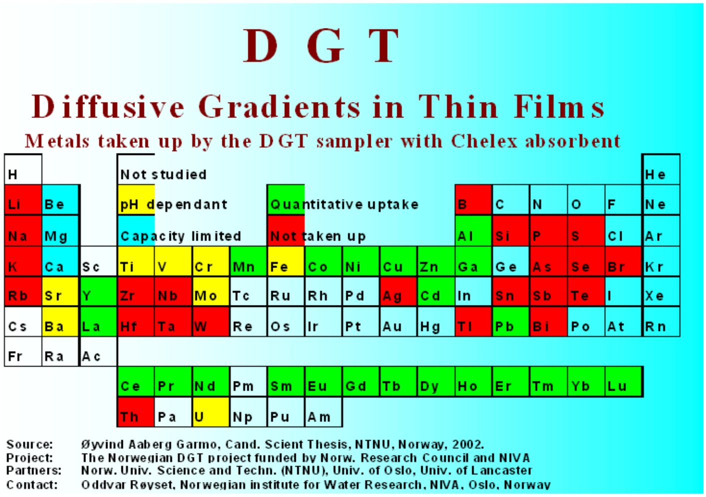


Figure 2. NIVAs DGT map showing the trace metals collected by the normal DGT sampler (Garmo et al. 2003)

2.2 Benthic Invertebrates are useful impact integrators

Benthic invertebrates (BI) are bottom/sediment living animals without backbones. They are constantly exposed to the current contamination of the water, and are used to monitor the environmental health of aquatic ecosystems such as lakes or streams. The advantage of using benthic invertebrate communities over chemical indicators to monitor the water quality, is that these animals are constantly "sampling" their environment. The benthic invertebrate communities are stationary and have a great varibility in tolerance limits. Thereby the community structures are indicators and integrators of water quality conditions.

2.3 Benthic Invertebrate Communities Indexes (BICI) for response

An indicator species is one that by its presence, absence, or abundance relative to other organisms, indicates environmental conditions. For example will numerous midges and worms (chironomides and oligochaetes) in a stream indicate severe organic pollution, while the absence of other species indicates metal pollution or low pH. The community structure of the benthic invertebrates may be pooled into Benthic Invertebrate Communitie Indexes (BICI). BICIs may express the ecological status, be used as spatial and time indicators of pollution levels in the recipient in a defined area.

2.4 Biomarker methods – new ecotoxicological assessments of stress level

Ecotoxicologists use molecular biological methods to describe effects. Macromolecules such as protein biomarkers are extracted from organism, and used as indicators of impacts. Classical indicators are metallothionins, the protein group used by organisms to scavenge toxic metals. The species best fit to produce metallothionins, are those most resistant to heavy metal pollution. Such biomarkers can explain why certain organisms are present or absent or how stressed they are, and thus describe the well-being or health status of exposed organisms.

3. RESEARCH GOALS

In the first phase of the project during 2007-2008, focus was on the use of DGTs. A PhD candidate started her work in 2009 focussing on a more integrated approach as visualized in figure 3 below:, a) The DGT (Diffusive Gradient in Thin Films) passive samplers to determine the toxic fractions of the heavy metals in the AMD water, b) use the benthic invertebrate community structures for BICI index developments and c) ecotoxicological biomarker methods to examine impact at organism level. The plan is to generate data sets for developments of new environmental impact assessment tools for organisms in aquatic ecosystems affected by AMD waters. The authors of this newsletter constitute the main project group at NIVA, CGS and UJ.

Impact of toxic metals	Impact at Community Level	Impact at Organism Level
DGT passive sampler	Benthic Invertebrate Biodiversity Indexes, BICI	Biomarkers by Ecotoxicological methods
		Methallo-thionins EROD ALA-D Oxidative stress Antioxidant enzyme CAT, GSH-Px, GST
Bioavailable fraction and toxicity dose integration	Detect and describe presence of indicator organisms	Stress level expression

Figure 3. Visualization of the Impact Assessment tools under development in this project.

4. RESULTS

4.1 New DGT samplers studied in AMD water at CGS

The classical DGT sampler (chelex metal adsorbent) and the new DGT sampler with a phosphate adsorbent (DGT-P, with a phosphonic acid paper disk), were compared. The DGT-P sampler is easier to use in dry areas such as in South Africa. The DGT-P sampler showed to be comparable to the classical DGT, for collection of important heavy metals in AMD water. DGT passive samplers have been little used in South African environmental research related to AMD. This project has improved both CGS and NIVAs experience on the use DGT-samplers. This is described in the publications below from the project.

4.2 The PhD study will educate a new specialist for EIA studies of AMD water

Vongani Mabokos PhD study started during 2009, and will when finished during 2013 educate a new specialist with experience on the use of DGTs, field studies, sampling, examination and indexing of benthic invertebrates and modern biomarker response indicator methods. More details of her study are explained at the CGS website:

http://www.geoscience.org.za/index.php?option=com_content&view=article&id=1291:the-use-of-aquatic-vertebrate-and-invertebrate-indicator-species-for-the-determination-of-acid&catid=124:projects-2010&Itemid=536

4.3 Publications from the project

Mengistu, H., 2009: *Application of DGT samplers in monitoring of mine waters of the Witwatersrand goldfields*, RSA, Council for Geoscience, Pretoria, South Africa, POSTER, International Mine Water Conference, Pretoria, RSA, 19 -23 October, 2009. Arranged by Water Institute of South Africa (WISA) and the International Mine Water Association.

Mengistu, H. 2009: *Passive samplers as long term monitoring tools in Witwatersrand goldfields*, Council for Geoscience, 280 Pretoria St,, Pretoria, South Africa, ORAL, Groundwater 2009 Conference, 16 -18 Nov, NH The Lord Charles, Somerset, West, Western Cape, RSA.

Mengistu, H., Røyset, O., Tessema, A., Abiye, T.A. and Demlie, M.B., 2012: *Diffusive gradient in thin-films (DGT) as risk assessment and management tools in the Central Witwatersrand Goldfield, South Africa,* Water South Africa Vol 38, No 1,, pp. 15-22.

Røyset, O., Iversen, E., Aanes, K.J. and Bjerkeng, B., 2009: *Water quality and metal transport in water-covered mine tailings deposits at sulphide ore mines – in situ measurements and modeling*, Norwegian Institute for Water Research (Norway), ORAL (by Royset), International Mine Water Conference, Pretoria, RSA, 19-23 October, 2009. Arranged by Water Institute of South Africa (WISA) and the International Mine Water Association.

5. RELEVANCED TO THE NORWEGIAN MINING COMMUNITY

The experience gained through this project for improved EIA tools of AMD water will be beneficial for the environmental research community in general, and not only for South Africa. The DGTs are good samplers for the toxic metal fractions, and valuable new tool for predictions of environmental impacts of heavy metals, and are useful tool for researchers working with mine water and AMD problems. Better knowledge of the toxicity of AMD waters will help to develop new and appropriate management and abatements actions of AMD waters. We believe the outcome of this project, and Mabokos PHD work, will be of value for also the Norwegian research community dealing with mine water problems, and may form basis for new knowledge development in this area.

5.1 Activities at NIVA related to effects of mining

NIVA have worked with projects related to mining operations both in in Norway and internationally through more than 50 years, with focus on effects in aquatic ecosystems especially heavy metal releases from the pyrite ore based mines, but also on particle loads from tailings, organic contaminations such as flotation chemicals as well as in more technical based remediation actions. More information about NIVAs research can be got from the NIVA authors, NIVAs research coordinator for mining activities John Arthur Berge (john.berge@niva.no), or from NIVAs website.

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