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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Sammendrag

Witwatersrand Central Basin Mine Water Apportionment Pilot Study (Witwater Prosjektet) er et FoU-prosjekt i samarbeid mellom Norsk institutt for vannforskning (NIVA), Council of Geoscience (CGS) i Pretoria, og University of Johannesburg med midler fra Norges forskningsråd og National Research Foundation (NRF) i Sør-Afrika under Forskningsrådets Sør-Afrika II-program (2007-2010). Formålet med prosjektet er å forbedre kjemiske og biologiske miljøkonsekvens utredningsverktøy for giftige tungmetaller i AMD (Acid Mine Drainage, surt gruvevann) vann fra gruver og gruvedrift med Witwatersrand Central Basin regionen i Sør-Afrika som testområde.

Summary

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 Uni-

versity 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 (2007-2010). The objective of the 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.

Background

The Witwatersrand region between Pretoria and Johannesburg

The Witwatersrand region situated at the South African inland plateau has been heavily mined during the last 150 years (http://en.wikipedia.org/wiki/Witwatersrand_Basin). Many operational as well as abandoned mines have high ingress of ground and surface waters, and abandoned return water dams thereby risking mine flooding and decant (overflow) of AMD water. The mine water has to be pumped and treated to reduce environmental effects in downstream recipients such as rivers, lakes and groundwater. The large amounts of AMD water produced, presumably reaching up to 90000 m^3/day, have been of grave economic and environmental problems for authorities, regulators and mine companies, and have caused considerable public outcry. This project team is attempting to introduce new environmental analytical chemical and biological monitoring methods for a better management of AMD waters. In the Witwatersrand region many mines uses vertical shafts down to depths of over thousand meters to access underground gold bearing horizons. The ground water table is typically at 10-30 meters and the water has to be continuously pumped to prevent mine flooding. Deep water 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 to high level of trace metals. Many dewatering pumping operations ceased in October 2008, and at present there are serious concerns that AMD waters from the flooding mines of the Central Rand Basin will decant into the ground and surface water reservoirs of the highly populated urban area of greater Johannesburg. Emergency and short-term plans are being implemented by the South African Department of Water Affairs to re-establish dewatering pumping and to construct a new treatment plant (Digby Wells & Associates, 2012, Inter-Ministerial Committee on Acid Mine Drainage (2010)).

Groundwater ingress to mines and tailing runoff forms AMD water

Oxidation of sulphide minerals exposed to air and water generate sulphuric acid and the production of AMD is especially strong in tailings from pyrite ores (such as Fe/Cu sulphides). Many other mined ores also bear considerable amounts of sulphides, so AMD is often a universal 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, 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 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 un-

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.

suitable also for other important purposes. 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.

Methods

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, was developed during the 1990ties (see Davison and Zhang (1994) and Davison et al (2000)). DGTs have been further developed at NIVA (Garmo, Røyset 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

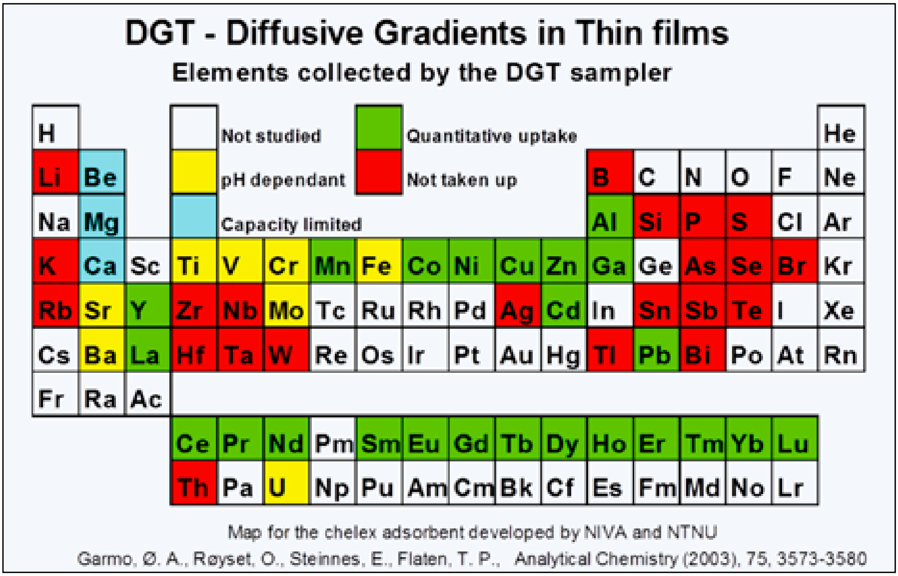

Figure 2. The DGT map shows the trace metals collected by the normal DGT sampler. Elements marked green have quantitative uptake over the normal pH range for water (4 - 9), while the uptake of elements in yellow depends on pH conditions (Garmo, Røyset et al. 2003).

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.

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 variability in tolerance limits. Thereby the community structures are indicators and integrators of water quality conditions.

Benthic Invertebrate Community Indexes (BICI) for response

An indicator species is one that by virtue its presence, absence, or abundance relative to other organisms, indicates environmental conditions. For instance, numerous midges and worms (chironomides and oligochaetes) in streams indicate severe organic pollution, whereas the absence of other species indicates metal pollution or low pH. The community structure of the benthic invertebrates may be pooled into Benthic Invertebrate Community 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.

Biomarker methods – new ecotoxicological assessments of stress level

Ecotoxicologists use molecular biological methods to describe effects at cellular or molecular level such as the presence of special enzymes. Macromolecules such as protein biomarkers are extracted from the organism, and used as indicators of impacts of stresses such as metals or low pH. 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.

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 objective 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.

Results

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. In addition to the classical trace metals, new DGT samplers suited especially for dissolved uranium are under field testing in the Greater Witwatersrand Goldfields by CGS. DGT passive samplers have been little used in South African environmental research related to AMD. This is described in the publications below from the project. The on-going capacity development is anticipated to educate a new scientist (PhD) and develop further knowledge of environmental scientists on the use of DGTs, field studies, sampling, examination and indexing of benthic invertebrates and modern biomarker response indicator methods. Some results are described in the publications below from the project.

The CGS website gives further details of the on-going PhD study of Vongani Maboko:
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

Impact of toxic metals	*Impact at Community Level*	*Impact at Organism Level*
DGT passive sampler	*Benthic Invertebrate Community Indexes, BICI*	*Biomarkers by Ecotoxicological methods*
		*Metallothionins* *EROD* *ALA-D* *Oxidative stress* *Antioxidant enzyme* *CAT, GSH-Px, GST*
Bioavailable fraction and toxicity dose integration	*Indicator organisms and community structure*	*Stress level expression*

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

Relevance 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 that Maboko's PHD work, and other knowledge developments, 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.

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 (Aanes, 1996). Project the last years have concentrated on long time monitoring of heavy metal discharges from Norwegian pyrite mines, abatements actions to prevent metal leaching from pyrite tailings in underwater tailing deposits (such as at Løkken), effects of metal discharges on freshwater fish and benthic communities in affected rivers, modelling of release rates of metals from water covered pyrite tailings, modelling of toxicity of metals in AMD affected waters on aqueous organisms, underwater deposition of mine tailings in Norwegian fjords, and international projects on environmental effect of mercury mine tailings in watersheds and other water related problems. More information about NIVA's research can be achieved from the NIVA authors, NIVA's research coordinator for mining activities John Arthur Berge (john.berge@niva.no), or from NIVA's website.

Publications from the project

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