Reliance on existing wetlands for pollution control around the Witwatersrand gold/uranium mines of South Africa - Are they sufficient?

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Abstract. The gold deposits of the Witwatersrand contain appreciable concentrations of uranium, which have at times been exploited commercially. Conditions downstream of mines have led to the development of extensive wetland systems, which have been shown to concentrate heavy metals including uranium and uranium series radionuclides from water discharged by mining operations and leachates derived from mine wastes. While these wetlands act as pollution sinks, geochemical simulations and models indicate that metals may be remobilised and pose a hazard to downstream water users.

Introduction

Since the commencement of mining activities in the Witwatersrand Goldfields in the late 19th Century, liquid effluents have been entering the natural surface and ground water systems. These effluents are a cocktail of the direct discharges of both process and fissure water from mines, run-off and infiltration from mine waste materials and contaminated areas and other industrial and domestic wastewaters from the cities and towns which have developed around the mining industry.

The salt and nutrient content of these waters has resulted in the development and maintenance of large wetland systems, which, while active and submerged tend to scavenge metals as well as organic contaminants from river water. Airborne radiometric survey data from the Witwatersrand confirm the concentration of uranium-series radionuclides in wetlands downstream of mines, while chemical analysis of sediment samples collected downstream of mines show concentration of uranium downstream of mining activities.

These observations raise three important questions regarding the efficacy of these wetlands in the mitigation of water pollution:

1. Are they currently effectively reducing pollutant levels to acceptable levels before the water reaches potential downstream water users under normal flow, drought and flood conditions?
2. Do the contaminants bound to wetland sediments remain in place, or is there a slow downstream migration of a contamination front?

If the water and salt inputs due to mining were to be stopped, and nutrient inputs from human settlements better managed, would the wetlands remain in place, and what would happen to the accumulated pollution due to more than a century of mining?

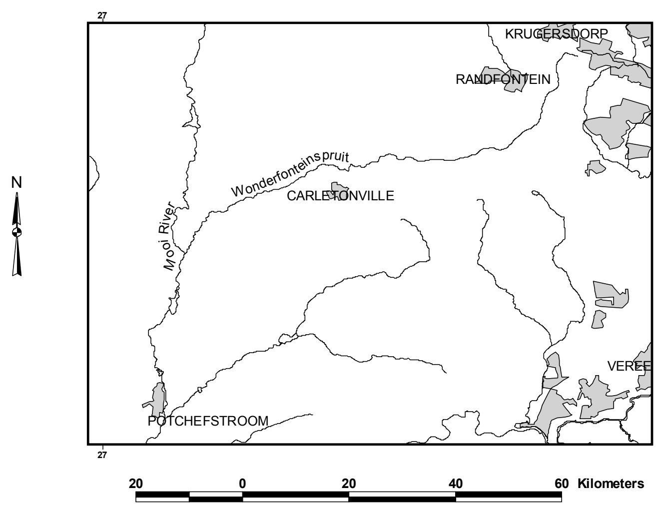

Fig. 1. Location of the Wonderfonteinspruit and Mooi Rivers, flowing towards Potchefstroom. The greatest concentrations of mining activities are in the Krugersdorp-Randfontein and Carletonville areas.

This study investigates the role of wetland sediments in pollution attenuation and possible remobilisation in the Wonderfonteinspruit Catchment. This river system (See Fig. 1) drains the mining areas of Krugersdorp, Randfontein and Carletonville. A large portion of the catchment is underlain by Proterozoic dolomites of the Malmani Group. The dolomitic environmental waters and the underlying rock play an important role in buffering the pH of the system, in contrast to other portions of the Witwatersrand basin where acid drainage is more common.

Current reduction of pollution levels

Adsorption and precipitation processes in the environment as well as dilution with environmental waters reduce pollution levels in streams in mining areas. A study conducted by the South African Department of Water Affairs and Forestry on the Mooi River System, during 1997-98 concluded that while radionuclide levels are elevated in streams in mining areas, water quality appears to improve downstream, with radionuclides posing a minimal hazard (IWQS 1999) to users in the town of Potchefstroom, downstream of the mines (See Fig. 1). In this study it was concluded that adsorption/precipitation processes in the environment reduced the radionuclide content of the water. It should be noted that a large portion of this area is underlain by dolomite, and the resulting neutralisation of acid minewaters will play a significant role in pollution mitigation. Other Witwatersrand mining areas, where the surface geology is not dolomitic appear to have significantly lower ability to attenuate mine-related water pollution.

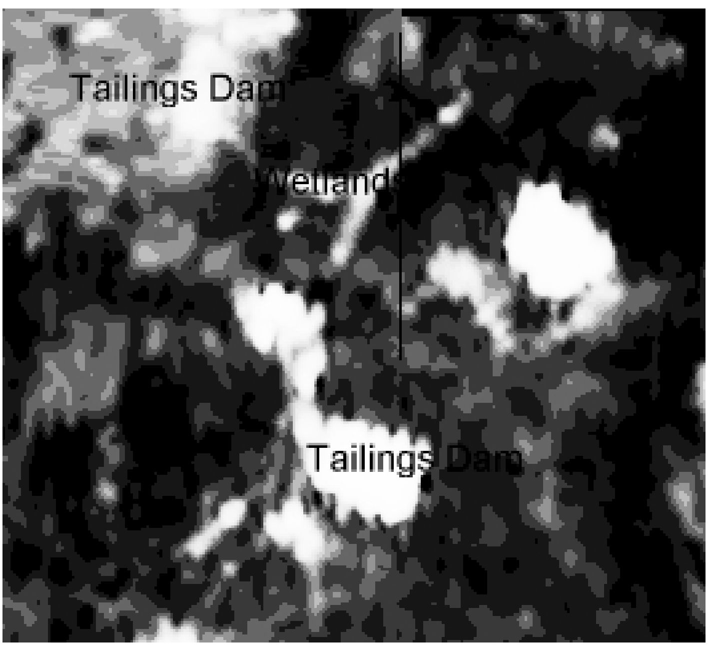

Fig. 2. Airborne radiometric image of a portion of the Wonderfonteinspruit Catchment, with lighter colours indicating higher gamma ray emission rates. Note the contamination of wetlands downstream of mining activities.

Ground and airborne radiometric surveys, as well as sediment sampling has shown uranium and other radionuclide levels in river sediments to be elevated above natural background levels several kilometers downstream of mining activities. Uranium concentrations above $10kBq \cdot kg^{-1}$ have been measured in farm dams and close to informal settlements. Whether or not these pose an immediate risk to the inhabitants of these areas or to people consuming agricultural produce from these farms has not yet been determined, but these levels of radioactivity exceed the legislated level for regulatory control of $200 Bq \cdot kg^{-1}$ (Wade et al. 2001).

Mobility of adsorbed metals in wetlands

To date, it has been believed that once adsorbed in wetlands, radionuclides and other metals will remain fixed in place. Recent studies have shown that the adsorbed phases of uranium in this system occupy a relatively narrow area in Eh-pH space. Sequential chemical extractions (Ure et al. 1993, Wade et al 2001) performed on sediment samples (See Fig. 3) have shown that changes in both pH and redox conditions within environmentally plausible ranges can release uranium and radium. Furthermore, these experimental studies indicate that uranium is bound to multiple sites in approximately equal quantities, so that any change in environmental conditions could release pollutants.

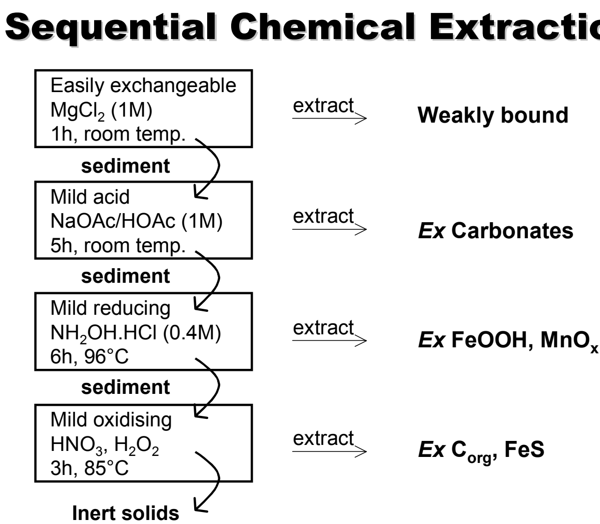

Fig. 3. Sequential extraction method used to determine the speciation of metals in sediment samples. The different extraction stages are used to simulate environmentally plausible conditions, which could impact on contaminated sediments

Sequential extractions as described in Fig. 3 have been performed on a suite of thirteen samples collected from a dam downstream of the Carletonville mining area. The samples were found to have a mean uranium concentration of 275ppm, using ICP-MS. The distribution of uranium between the different phases in the sediment is indicated on Fig. 4.

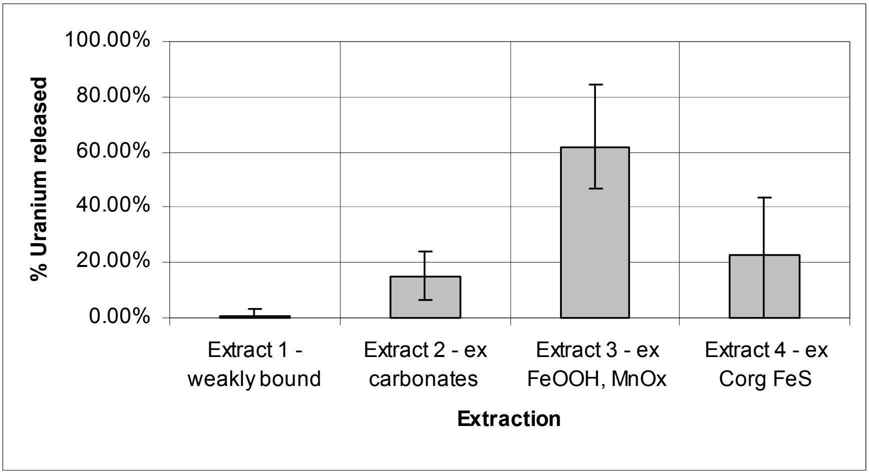

Fig. 4. Percentage uranium released from thirteen samples in a sequential extraction, as described on Fig. 3. Vertical bars indicate the mean percentage of the total uranium per sample released, while error bars show the range of percentages released.

These results indicate that most of the uranium is bound to FeOOH and MnO_x complexes, but that a significant proportion is bound to carbonates and in reduced phases on organic carbon or pyrite. Scanning electron microscope studies have shown that the pyrite within the sample is authigenic, indicating that the transport of uranium is in a dissolved phase, rather than as particulate derived from mining and milling of ores.

The long-term future of polluted wetlands

Many wetlands downstream of current mining areas are fed by water pumped from operating mines. Large quantities of nutrients also enter these systems from informal settlements, overloaded or poorly maintained sewage treatment works and industries. As formal housing becomes available, old sewage works are upgraded, higher environmental standards are imposed upon industry and mines discontinue pumping, it is possible that the water and nutrient inputs into wetlands may be reduced. Previously non-perennial rivers where flow has been maintained by mine dewatering could once again dry up during the dry seasons, exposing the wetlands and allowing oxidation to release adsorbed contaminants.

Mine closure poses an additional long-term environmental hazard. Contaminated areas outside of mine properties may not be subjected to the same type of regulation or restriction as those on mines. This could lead to the use of old contaminated sites for agricultural or other purposes in the future, after the financial responsibility for clean-up has been transferred to the State. The areas in question, as well as the volumes of material and nature of contamination could place a significant burden onto future generations.

Conclusions and recommendations

Wetlands have proved an excellent means to attenuate pollution from Witwatersrand gold/uranium mines. The uncontrolled manner in which this has been allowed to happen is however of extreme concern. Firstly, it has allowed to build-up of contamination on private and public land off mining properties and secondly it has happened in a haphazard and uncontrolled fashion. Artificial wetlands may offer a partial solution to problems related to discharge of water on these mines, but it should be borne in mind that the cost of maintenance and monitoring should be borne by the polluters and that the eventual fate of the contaminants should remain the responsibility of the mines involved.

The sequential extraction study undertaken shows that while wetland sediments have a significant capacity to adsorb and immobilise pollutants, plausible chemical conditions may also lead to the remobilisation of these pollutants. The reservoirs of contaminants stored downstream of mining activities could therefore pose a long-term risk to downstream water users.

The processes that concentrate radionuclides in sediments also concentrate gold. Consequently, decontamination of contaminated sites may be able to generate sufficient revenue to partially fund rehabilitation. The current trend is however to limit rehabilitation to those areas where gold concentrations make rehabilitation profitable, neglecting less gold-rich areas unrehabilitated. An holistic approach is needed, where environmental priority areas are also rehabilitated.

References

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