Rapid field based analytical techniques for the environmental screening of abandoned mine sites

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Abstract South Africa's long mining history has left a legacy of over six thousand abandoned mine sites, many of which are the results of the mining of materials which may have a negative impact on local surface streams and aquifers A field-based screening protocol for the assessment of water quality and the potential of solid materials to pollute has been assembled using commercially available consumable water tests and procedures requiring the minimum of specialised capital equipment and optimised for implementation by relatively unskilled field workers. Where needed this can be complemented with more sophisticated field and laboratory-based methods.

Keywords Field analysis, screening level assessment

Background

South Africa has a long history of mining, with formal records extending back to the 17th Century and archaeological evidence of mining extending further back into the past. This has left a legacy of over six thousand abandoned mine sites (Coetzee *et al.* 2008), many of which are the results of the mining of materials which may have a negative impact on local surface streams and aquifers. In order to manage these impacts, a programme has been initiated to assess the impacts of these sites on local communities and the surrounding environment and to identify high-priority sites for remedial action. As a water-stressed country the impacts on water need to be taken seriously.

Since 2005, the Council for Geoscience (South Africa's Geological Survey) has been undertaking research into the impact of these abandoned mines, with the aim of advising the country's Department of Mineral Resources – the government department legally responsible for addressing the impact of mines where no legally liable party can be identified – on the management of this problem. The primary activities have included the compilation of a detailed inventory of affected sites, the assessment of the hazards and risks posed by these sites to affected communities and the environment and the identification of priorities for remedial action and rehabilitation. More recently, this scope has expanded to include the implementation and management of rehabilitation projects.

Initial investigations undertaken on a number of sites have indicated that water contamination is not ubiquitous, even in cases where potentially polluting minerals such as sulphide hosted gold, copper, lead and other metals, uranium or sulphide-rich coal were mined. Pollution is not only a result of the commodity mined and mineralogy of the deposit but also depends on the local chemical and hydrological conditions which promote or inhibit immobilisation of pollutants and the rate of reactions.

Previous screening studies, based on simple models of the potential impacts of mineralised zones on the groundwater environment (Sami and Druzinski 2003) proved to be inadequate to predict water qualities (Tarras-Wahlberg *et al.* 2008) and identified the need for analysis of water samples and a suite of laboratory tests to characterise rock-water interactions.

Screening methods

The large number of sites to be assessed requires a screening protocol which will identify priority sites and areas rapidly, providing the necessary rigor to allow the identification of sites of minimal concern and lower priorities. In practice, the elimination of a site from the list of sites of concern is often more difficult than the identification of priority sites for remediation as it entails the elimination of concerns, rather than the identification of problems.

In screening large numbers of sites in a relatively short time, an approach is proposed which fulfills a number of criteria, based on the types of hazards posed by mining sites and the context of these sites within the South African environment.

- Field-based techniques provide which can rapidly provide sufficient information to allow the identification of problematic and non-problematic sites are preferable, as these allow field teams to focus on data collection in areas where data are required for potential future remediation actions.
- Rapid methods allow sufficient productivity to allow the assessment of several sites within a limited amount of time. In the screening phase it is preferable to screen more than one site per day.
- Field analyses need to be sufficiently comprehensive to cover key contaminants in the areas of interest. Existing knowledge of ore types and mineralogy and likely contaminant species can allow the selection of an analysis set for a specific mineral province.
- The analytical tools used need to have sufficient sensitivity to allow the identification of pollution. The detection limits of methods need to be of a similar order of magnitude to water quality targets or appropriate limits, while accuracy and precision should be adequate for at least a semi-quantitative analysis.
- Costs should be at best comparable with laboratory analyses.

South African organisations face a number of other challenges with respect to the analysis of large numbers of samples in screening studies. Laboratory facilities are relatively limited, leading to comparatively high analytical costs and long lead times for analyses. The lead times are a particular problem for the rapid screening needed in the assessment of large numbers of contaminated sites in a relatively short time.

Historical and recent factors have contributed to a situation where South Africa suffers an acute shortage of technically skilled personnel. Lawless (2008) reports that in the case of civil engineering professionals, South Africa scores poorly in a comparison of number of engineering professionals relative to the country's population. Many South Africans are not exposed to science laboratory work at all during their schooling. Tsipa *et al.* (2010) report that, in a sample of high school learners in Mpumalanga Province, 58 % of respondents had no laboratories in their schools and 75 % had no science equipment. A shortage of skilled teaching staff at schools level (Segar 2012) exacerbates this problem, and is likely to hamper the implementation of complex technical processes compound the relative lack of laboratory facilities on an extensive scale in South Africa into the future. Methods based on simple procedures which produce unambiguous results are therefore of great use in the South African context.

Complementary analytical methods

Often, the questions which require answering on a mine site go beyond a simple water analysis. In many areas, water quality will vary seasonally, much of South Africa being semi-arid, with large seasonal variations in precipitation. In many cases, sites are visited where no runoff is available for sampling, while physical evidence of seasonal as well as episodic runoff exists. Furthermore, determination of the pollution potential of a site is generally also critical. To this end, a suite of laboratory methods have been devised, starting from very basic

Analysis	Detection limit	Ranges
pH		2-9 (resolution 0.5)
Fe	2 mg/L	2-100 mg/L
	5 mg/L	5-1000 mg/L
SO_4	200 mg/L	200-1600 mg/L
Al (test strip with additional reagents)	5 mg/L	5-500 mg/L
Zn	2 mg/L	2-100 mg/L
Ni	10 mg/L	5-1000 mg/L

Table 1 *Analytical tests used in evaluation of the suitability of rapid tests for mine water screening*

batch methods to kinetic tests which are undertaken over a long term under controlled laboratory conditions (INAP 2013).

Rapid field screening can also be applied to samples collected in pollution prediction studies in the field. This adds detail to field screening methods. Methods where field analysis could be of value include field-based leach tests such as paste pH and the USGS Field Leach Test (Hageman 2007) and face washing (INAP 2013) as a means to predict leachate and runoff quality. Where possible, these tests should avoid the use of specialised equipment.

Where greater precision is required, more advanced colorimetric methods, requiring the use of a field-portable spectrophotometer may also be employed.

Assessment of preliminary testing

As a preliminary step, a number of test methods were identified and test kits (Macherey-Nagel 2012) purchased. The majority of these are based on a simple test strip which is dipped into a liquid sample and the concentration range within the sample determined by matching the colour(s) of one or more indicator patches to a standard chart, generally printed on the test strip container. For some elements test strips need to react with one or more reagents, typically supplied in powder form as part of a test kit. In the current study, only Al required additional reagents.

Assessments have been undertaken for analysis of pH, Fe(total), SO_4, Al, Zn and Ni on leachates generated from sulphide-rich rocks from the Witwatersrand Supergroup. These all have sufficient sensitivity to detect pollutant concentrations found in Witwatersrand mining environments (Coetzee *et al.* 2006; Hobbs *et al.* 2011) as well as having detection limits similar to typical regulatory limits for mining discharges (see Table 1). Furthermore, the different concentration ranges have been shown to be effective in ranking more or less polluted samples.

Applications

Field screening

The key application intended for these tests was for the rapid screening of sites in the field to allow field investigators to focus their attention on sites where preliminary studies demonstrate significant water contamination or contamination potential.

In-situ analyses

In other areas, *in situ* analysis provides the opportunity to recommend precautions based on water quality. This has specific application in areas where communities may be directly and immediately affected by contamination from mine sites. Rapid tests are also useful in the evaluation of passive treatment systems and natural attenuation in the field.

Laboratory applications

Rapid tests have direct application in laboratory studies and leach tests. Often rapid semi-quantitative results provide the necessary information to design lab testing programmes for a suite of samples without waiting for more precise laboratory data. In the process of demonstration of laboratory techniques and results, rapid analyses can often be used to illustrate processes in real-time.

Community-based monitoring programmes

In recent years, South African community and advocacy groups have shown progressively more and more interest in becoming actively involved in environmental monitoring programmes. Given the shortage of technically skilled personnel in regulatory and research institutions, this presents a real opportunity and rapid field tests have potential to enable meaningful monitoring. Conventional field instrumentation, despite simplicity of operation requires calibration and maintenance which may be beyond the level of available skills. Field equipment is also relatively expensive, limiting the number of sites where this can be deployed in communities.

The rapid methods explored in this study require no capital equipment and are relatively cheap. This makes it possible for kits to be deployed in communities, enabling them to perform at least rudimentary tests on local water and become involved in local water quality monitoring programmes.

Quality assurance and quality control

The field-based screening methods described rely largely on QA/QC procedures which form part of the production of the kit. Provided that proper training is provided to the operators and that the manufacturers' instructions are adhered to, most methods are relatively robust.

In preliminary testing, it has been found to be advantageous to photograph the test strips as a record of the laboratory results. If necessary, the standard colour scales can be included in this for comparison purposes. Digital cameras also record the time and date of the photograph and in many cases, the location, via a linked GPS receiver. In practice it has been found that a good quality mobile phone camera provides adequate image quality for this (Fig. 1).

Limitations

A number of limitations have been identified in the initial method testing phase.

1. Interpretation of some of the colour-based tests relies on identification of relatively subtle colour changes, although training and experience does permit a reduction in possible ambiguity. This may be of particular importance where test kits are provided to community groups. A photographic record of tests, as described

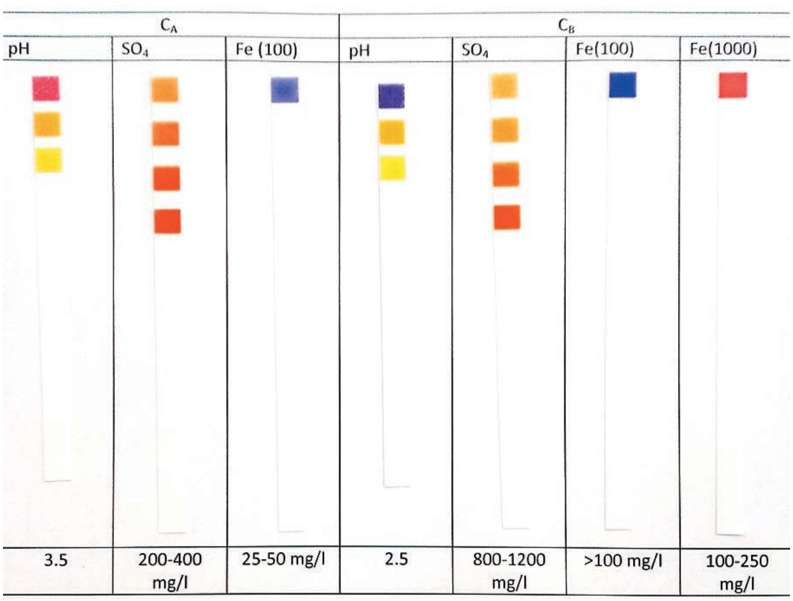

Fig. 1 *Photographic record of a test strip analysis of two leachate samples, C_A with relatively lower levels of contamination than C_B.*

above, may minimise possible ambiguities.

2. Obviously, this method does not provide a full suite of analyses for mine water. The most significant gap in the current analytical procedure is a proxy for total dissolved solids, although in many South African mining areas where water quality is well understood and characterised, the combination of SO_4, Fe and Ca may allow assessment of total salinity. Even where sufficient major elements are analysed, the relatively poor precision of each measurement will combine to provide poor data on total dissolved solids.
3. The ability to use field techniques to analyse trace elements at low levels is relatively limited, although arsenic test kits are available with detection limits as low as 0.005 mg/L.

Conclusions and recommendations

A field-based screening protocol for the assessment of water quality and the potential of solid materials to pollute has been assembled using commercially available consumable water tests and procedures requiring the minimum of specialised capital equipment. Where needed this can be complemented with more sophisticated field and laboratory-based methods. The method aims at the screening of sites to allow the identification of sites where little or no remediation is required to address water contamination, rather than the detailed characterisation of contaminated sites. The methods used do however need adequate detection accuracy and precision at concentrations appropriate for screening-level assessments.

An additional objective of this approach has been the identification of simple test procedures which can be implemented by non-specialist operators who may lack access to laboratory facilities and sophisticated equipment allowing qualitative to semi-quantitative water quality testing to be undertaken on a broader scale than would be possible given the shortage of skilled personnel in the country.

Over time, a suite of laboratory methods has been developed for the analysis of mine wastes and the prediction of water pollution (Sobek *et al.* 1978). Some of these may be undertaken in the field to expedite the screening of sites. Field screening is ideally suited to direct water analyses or the analysis of leachates produced during field tests which may be performed in relatively short times. This can be used to facilitate the rapid screening of sites where this is deemed necessary and the required test methods provide the necessary accuracy and precision.

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