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River catchment responses to anthropogenic acidification in relationship with sewage effluent: An ecotoxicology screening application

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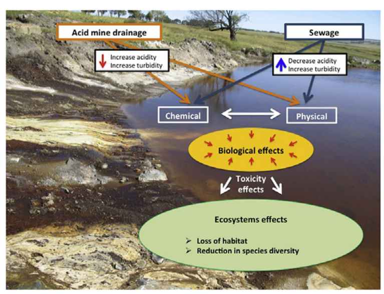
HIGHLIGHTS

- Acid mine drainage (AMD) and acid precipitation identified as most important drivers of acidification.
- Acidification in river system using aquatic organisms at different trophic levels were only evident in areas of AMD.
- Ecotoxicology screening tools, revealed that discharge of sewage partially mitigated effects from AMD and acid precipitation.
- Indicator organisms indicated high loads of sewage effluent might neutralize effects from AMD and acid precipitation.
- Findings are important for integrated water resource management on catchment level.

GRAPHICAL ABSTRACT



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ABSTRACT

Rising environmental pressures on water resources and resource quality associated with urbanisation, industrialisation, mining and agriculture are a global concern. In the current study the upper Olifants River catchment as case study was used, to show that acid mine drainage (AMD) and acid precipitation were the two most important drivers of possible acidification during a four-year study period. Over the study period 59% of the precipitation sampled was classified as acidic with a pH value below 5.6. Traces of acidification in the river system using aquatic organisms at different trophic levels were only evident in areas of AMD point sources. Data gathered from the ecotoxicology screening tools, revealed that discharge of untreated and partially treated domestic sewage from municipal sewage treatment works and informal housing partially mitigate any traces of acidification by AMD and acid precipitation in the main stem of the upper Olifants River. The outcome of the study using phytoplankton and macro-invertebrates as indicator organisms revealed that the high loads of sewage effluent might have played a major role in the neutralization of acidic surface water conditions caused by AMD and acid precipitation. Although previous multi–stage and microcosm studies confirmed the decrease in acidity and metals concentrations by municipal wastewater, the current study is the first to provide supportive evidence of

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this co-attenuation on catchment scale. These findings are important for integrated water resource management on catchment level, especially in river systems with a complex mixture of pollutants.

1. Introduction

The eutrophication and acidification of surface waters have become an endemic global problem. Nutrient loads from sewage treatment plants, agriculture activities and acidity from acid mine drainage and acid precipitation is major drivers, but it remains unclear how they interact on catchment level (López-Doval et al., 2012; Withers et al., 2014). The Olifants River, South Africa as case study has a number of strategically important water use activities that take place (Oberholster et al., 2013a). These activities rely heavily on a variety of goods and services derived from the aquatic ecosystems in the catchment to sustain their processes. However, the Olifants River system has been described as one of the most polluted rivers in southern Africa due to the intensity and variety of land use activities that are present, particularly in the upper catchment, and the changes to water quality that have resulted from these activities (Grobler et al., 1994).

South Africa is the world's sixth largest coal producer (22 Mt coal per year) (DME, 2004). The largest area of current coal mining in this country is within the upper Olifants River catchment, where there is also considerable electricity generation (Tshwete et al., 2006). Abandoned flooded or spontaneous combusting mines are decanting up to 50 Ml/d of acid mine drainage (AMD) that is mostly untreated and contaminates ground and surface waters (McCarthy, 2011). Air pollution from the burning of nitrogen oxides (NO_x) and sulphur dioxide (SO_x) and other pollutants contaminates rain that in turn contaminates water (Bell et al., 2002).

Low pH and metals from AMD adversely affect the structure and functioning of aquatic systems affecting productivity, abundance in biomass or may result in complete elimination of aquatic species (Økland and Økland, 1986; Winterbourn et al., 2000). The toxicity or metals accumulation in aquatic organisms pose a health risk to aquatic organisms and people consuming these organisms (Cherry et al., 2001).

Elevated concentrations of metals including Al and Fe are characteristic in many AMD contaminated streams (Winterbourn et al., 2000). Al in particular is a highly toxic metal at low pH ranges. The latter is commonly released via processes such as AMD and acid precipitation (Dise et al., 2001; Oberholster et al., 2013c).

Usually, atmospheric precipitation provides a dilution effect on contaminants within a river system (Martins et al., 2007). However, atmospheric precipitation can become acidic due to anthropogenic activities. Acid precipitation is caused by the emissions of SO_2, primarily from fossil-fuel power stations and metal smelters, while NO_x is caused from industrial sources and power plants forming sulphuric and nitric acid, carbon and base metals in precipitation (Conradie et al., 2016). Typical pH values of acid precipitation caused by anthropogenic emissions may be in the range of 3.5–5.6 (Wang, 2008). In addition to wind direction and distance from the source, wet deposition depends on a number of factors, including the amount of precipitation and rate of SO_2 oxidation (Menz and Seip, 2004; Huston et al., 2009). Therefore, it is important to understand what the impact and consequences of these and other pollutants are in order to protect and manage aquatic ecosystems and the goods and services that they provide.

According to Karr and Chu (1999), water column chemistry alone may only give a snapshot view of stream conditions and do not provide an integrative measure of the overall health of aquatic ecosystems (Barbour et al., 1999). To overcome this shortfall, bioindicators from different trophic levels in the aquatic foodweb are often utilised as ecotoxicology screening tools to determine impacts such as acidification of aquatic systems (Karr and Chu, 1999). Benthic macroinvertebrates and Diatoms as indicators are widely distributed in lotic and lenthic systems and are the most popular and commonly used group of freshwater organisms in assessing water quality (Dabrowski et al., 2014; Bray et al., 2008; Oberholster, 2011).

A key advantage of *ex situ* toxicity testing is that it detects toxic compounds based on their biological activity without any prior knowledge required of the toxicant to identify its presence (Leusch and Chapman, 2011). One of the widely used invertebrate species recommended for acute or chronic toxicity testing is the cladoceran *Daphnia magna* (Parlak et al., 2010). Algae on the other hand are selected as test organisms because they are the dominant primary producers in the aquatic food chain (Finlay et al., 2002). Although there are numerous studies on the impact of atmospheric acid precipitation and AMD on water resources in literature, very little is known about the impacts of a combination of these stressors in tandem with domestic sewage and agriculture activities on the aquatic environment. Thus, the objectives of the current study were to used the upper Olifants River catchment as case study to: (a) establish the current state of the aquatic ecosystems affected by acidification by using different aquatic indicator organisms as screening tool, and (b) to determine the response of the system to a mixture of AMD and acid precipitation in tandem with domestic sewage effluent and agriculture activities at sub-catchment scale.

2. Materials and methods

2.1. Study area

The Olifants River catchment is under severe water stress with the demand for water exceeding the available amount due to multiple land use activities in its catchment (Oberholster et al., 2010). The total upper Olifants River catchment area is 11 464 km^2, with a mean annual precipitation of 683 mm and a mean annual runoff of 10 780 Mm^3 (Midgley et al., 1994). In the upper catchment, coal has been mined for more than a century, and is being exported and used locally in coal-fired power plants. As a result large numbers of AMD decanting abandoned mines occur, as well as coal related industries, such as steel and V producers and coal washing plants (Peatfield, 2003). The social and economic development of the upper catchment is strongly based upon coal mining, coal combustion power plants, smelters and several industries using coal as energy. The nine power stations in the region provides 90% of the electricity for South Africa (Burton and Winkler, 2014), while Ferrometals near the city of Witbank, is one of the largest individual ferrochrome plants in the world and produces chrome for the steel markets. A previous study by Josipovic et al. (2011) showed that large portions of the industrial infrastructure is concentrated on the Highveld plateau which include the upper Olifants River catchment and accounts for approximately 90% of South Africa's scheduled emissions of industrial dust, sulphur dioxide and nitrogen oxides. South Africa is also regarded as the ninth