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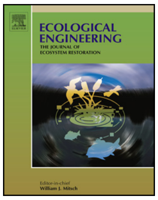

The effect of rehabilitation measures on ecological infrastructure in response to acid mine drainage from coal mining

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ABSTRACT

Water treatment is an important ecosystem service in natural systems and wetlands are well-known to have increased functionality in this regard. The rehabilitation of productive wetlands plays an important role in improving this functionality in degraded wetlands, but it is not well-known to what extent these activities improve acid mine drainage impacted waters. The aim of this study was to evaluate the significance of the effect of such interventions on the ecological functioning of a test wetland affected by acid mine drainage. A degraded wetland influenced by acid mine drainage in the Mpumalanga Province of South Africa was identified for the case study. This site was rehabilitated using a variety of hard (e.g., weirs/dams) and soft (e.g., earth berms) structures and examined to determine whether its ecological functioning (i.e., the improvement of water quality) and biotic community structures have improved. From the results it was evident that a substantial improvement in water quality occurred below the rehabilitated area, even though the wetland still continued to receive acid mine drainage. This was observed through the decrease in metal pollution in conjunction with an increase in pH and alkalinity levels. This resulted in increased productivity, reduced toxicity (embryotoxicity and teratogenicity), as well as changes in the biotic community structures which were a reflection of a less polluted environment. The study has shown that the rehabilitation of ecological infrastructure can be used to mitigate the effect of coal mining related pollution such as acid mine drainage. In the face of ever increasing land use activities that occur globally to meet the demands of growing populations, this information can be useful to mitigate negative residual influences resulting from these activities, e.g. acid mine drainage.

1. Introduction

Ecological infrastructure refers to naturally-functioning ecosystems (e.g., wetlands) that generate and deliver valuable services to people. It is the nature-based equivalent of built or hard infrastructure and can be just as important for providing services and underpinning socio-economic development (SANBI, 2014). It is well-known that anthropogenic activities can have adverse effects on aquatic ecosystems (Carpenter et al., 1998). The effects of activities such as opencast coal mining that result in a decrease in ecological services provided by these systems, have also been well-documented (Boyer and Wratten, 2010). Both direct and indirect ecosystem services are tangible and typically linked at a broader landscape or catchment scale, such as regulating various ecological processes which contribute to the integrity of ecosystems and a healthy environment (Kotze et al., 2009a; Macfarlane et al., 2014). The upper Olifants River in the Mpumalanga Province of South Africa is a good example of an aquatic ecosystem negatively influenced by, inter alia, intensive coal mining activities (Hobbs et al., 2008). As a result of these anthropogenic activities, it has been described as one of the most polluted rivers in southern Africa, especially due to the effects of acid mine drainage (AMD) (Grobler et al., 1994).

The numerous land use activities taking place in the upper Olifants River catchment rely heavily on ecological services produced by this river and the surrounding wetlands (Dabrowski and De Klerk, 2013). Wetlands provide more ecosystem services per

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hectare than any other ecosystem, being sites of intense biogeochemical activity that play an important role in improving water quality (Lischeid et al., 2007; Tauchnitz et al., 2010). However, by virtue of their positions in the landscape and relationship to drainage networks, wetlands are frequently affected by coal mining activities, especially opencast methods (Hobbs et al., 2008; Ochieng et al., 2010; Silva et al., 2011). These effects will be ongoing, since coal is a strategic resource in South Africa and will continue to be mined extensively to support the country's development (Hall, 2013). At the same time however, regulatory authorities and the public now have a greater, more informed understanding of the range of economic, social, ecological and hydrological costs of wetland loss and degradation.

The benefits of investing in the maintenance and rehabilitation of ecological infrastructure are also becoming more evident as research in this domain continues (Fennessy and Mitsch, 1989; Baker et al., 1991; SANBI, 2014). Globally, several different approaches have been used for the rehabilitation of wetlands (Pfadenhauer and Grootjans, 1999; Russel, 2009). The rehabilitation of wetlands focuses on improving wetland ecosystem structure and function, thereby improving the ecological integrity of the system (McKenna, 2003; Porter and Nairn, 2008). This methodology incorporates the physical, chemical and biological components of a wetland ecosystem at different trophic levels. At present, the Highveld and Witbank coalfields in the catchment of the Olifants River are the source of more than 80% of South Africa's total coal outputs (Hancox and Götz, 2014). However, these coalfields are nearing depletion and as a result, the relocation of operations to other parts of the country, such as the Waterberg coalfields in the Limpopo Province of South Africa, is being planned for the near future. A geological assessment has shown that the Waterberg has the potential to generate AMD and proper mitigation strategies should thus be in place if the need arises (Bester and Vermeulen, 2010).

The capacity of a biological system to sustain an integrated and adaptive system is known as ecological integrity. Maintaining the ecological integrity allows for the sustainability of the full range of elements and processes occurring within such a system (Innis et al., 2000). Monitoring the ecological integrity of ecological infrastructure is beneficial as it allows for an indication of the integrated effect of the activities taking place in a specific catchment (Niemi and McDonald, 2004). As it is not practical to monitor each parameter associated with an aquatic ecosystem in detail, certain indicators (biotic and/or abiotic) are used as an indirect indication of the integrity of the ecosystem (State of Rivers Report, 2001; Wolkersdorfer, 2012). Microorganisms (e.g. bacteria) play a vital role in the biogeochemical recycling of wetlands and are very important for the removal of pollutants (Gutknecht et al., 2006; Faulwetter et al., 2009). Many species are capable of functioning under both aerobic and anaerobic conditions and respond to changing environmental conditions (Kirchman, 2002; King et al., 2013). They can therefore be ideally used as indicators of the parameters affecting wetland functioning, like low pH (Tian and Hua, 2010; Bueche et al., 2013).

On the other hand, algae are primary producers and therefore at the base of most aquatic food webs (McCormick and Cairns, 1994). They have been used as water quality indicators in various biomonitoring tools (Taylor et al., 2007), providing useful time-integrated water quality information, as they can respond rapidly to water quality changes (Bate et al., 2004), especially since many algal species have specific ecological, chemical and physical preferences (Bellinger and Sigee, 2010). Monitoring the teratogenic potential and embryotoxicity of surface waters have also been widely implemented to monitor the effects of pollutants in aquatic ecosystems (Tietge et al., 2000). This is especially important to evaluate the developmental toxicity linked to AMD (Dawson et al., 1985) and therefore provides useful information to the quality and risk of ecological infrastructure (Hoke and Ankley, 2005).

As coal mining will continue in South Africa, there is a need to determine whether wetland rehabilitation can improve degraded water qualities received from AMD and as such improve the ecological infrastructure. The objective of this study was thus to evaluate the outcome of wetland rehabilitation methods on the water quality and ecological integrity of the aquatic ecosystem influenced by coal mining activities. The outcomes of this research is of global importance since the sustainable development of our natural resources are crucial to a growing population, especially when considering the exploitation of the virgin coalfields in the Waterberg region of South Africa. It will also improve the ability to manage already exploited areas, such as the Olifants River basin, and aid its recovery. Thus, the aims for this study were to: (a) determine the degree of improvement in selected water – and sediment quality parameters; (b) determine the effects of the rehabilitation efforts on the ecological integrity through the evaluation of the changes observed in the bacterial and algal assemblages; and (c) determine the changes in the embryotoxicity and teratogenicity potential of the surface waters which can be linked to human health.

2. Materials and methods

2.1. Study area

The Grootspruit Wetland (25°54′25.93″S; 29°3′12.09″E, WGS84) is a tributary of the Zaalklapspruit Wetland system and is situated in the upper Olifants River catchment of the Mpumalanga Province of South Africa (Fig. 1). The portion of wetland selected for rehabilitation has been affected by historical cultivation and artificial drainage resulting in channel incision, as well as high concentrated flows (>0.5 m/s) through the wetland. These concentrated flows reduced the ability of the wetland to filter and clean the water flowing through it. In addition, the wetland receives AMD from an upstream coal mining operation. Study sites were strategically selected above and below the conglomeration of interventions in the rehabilitation area (described below), along with a suitable reference site higher up in the catchment. The objective with the site selection was to obtain an understanding of the difference in water quality entering and exiting the rehabilitated area. A general overview of ecosystem characteristics of the upstream, downstream and reference sites were determined according to Kotze et al. (2009a) and Oberholster et al. (2014a) and is presented in Table A, Supplementary material. The study area falls within a summer rainfall region (thus receiving rain mostly from November to February). Samples were collected during this period, before and after rehabilitation, in order to avoid the influence of seasonal dynamics. Three sampling trips were undertaken during this period at the selected sites prior to rehabilitation (2012/2013) and, once rehabilitation was completed, three post-rehabilitation sampling trips were additionally conducted (2013/2014). The results obtained from the two sites upstream and the two sites downstream were pooled to give an overall picture of the conditions of the upstream and downstream areas both before and after rehabilitation. The results from the reference, upstream and downstream sites before and after rehabilitation are referred to as follows: Ref-Pre, Ref-Post, Down-Pre, Down-Post, Up-Pre and Up-Post.

2.2. Rehabilitation interventions

The Grootspruit Wetland is a naturally un-channelled valley bottom wetland system (≈140 ha). Based on the fact that the main aim of the rehabilitation project was to investigate the ability of