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Research article

Towards a rapid assessment protocol for identifying pit lakes worthy of restoration

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ABSTRACT

Before the introduction of reclamation legislation in South Africa, final cut lakes in mining areas were left without any restoration while the final excavation was not back filled. Characteristics of these lacustrine water bodies vary considerably, but they are often linear in shape, large (1–30 ha), deep (2–30 m) and have poorly developed littoral zones. With water tables often near the surface; a variety of vascular hydrophytes can colonize these bodies, thus establishing emerging wetland type ecosystems. These, man-made aquatic structures that are (unintentionally) created potentially offers some realistic and inexpensive mitigation options for some of the negative impacts associated with mining, i.e. these water bodies can become useful by yielding potentially valuable services. However, no method currently exists to compare and rank these water bodies according ecological integrity and the expected monetary value to be derived from them in order to select sites for restoration. To answer this need, we applied an index to determine the ability of these water bodies to provide useful services in their current state. The index was then used to derive estimates of the monetary value of potential services in order to allow comparison with the cost of restoring the water body in question or to compare with other pit lakes. We present a South African case study to illustrate the method. As far as could be established, this is the first attempt towards creating a rapid assessment tool as standardised way of comparing pit lakes that allows for the ranking and identification of those pit lakes worthy of restoration.

1. Introduction

Although mining remains a major catalyst for economic development, it also has a legacy of perpetuating environmental impacts. Water pollution (salinization in particular) and the disruption of water ecosystems due to riverine tailings, tailing impoundment releases, and acid mine drainage from abandoned mines, are of particular concern.

Over 6000 abandoned or ownerless mines in South Africa require rehabilitation at an estimated cost of $3 billion and ongoing maintenance cost in excess of $1 billion per annum (Genthe et al., 2017). This mining legacy problem is not unique to South Africa and whilst the mining sector has become more socially and environmentally conscious, it remains a major problem for the country. Ample opportunity (bolstered mainly from new reclamation legislation) for innovative interventions that goes beyond mitigating risk and more towards socially and economically inclusive development solutions remains.

One of such is the restoration of pit lakes in order to derive some benefit to society from these otherwise unwanted water bodies. These water bodies are created when final cut lakes in mining areas are left without any restoration while the final excavation is not back filled. These new aquatic bodies are then formed by the natural filling of water during the post mining phase. Although the characteristics of these bodies vary significantly, they are typically deep with a narrow or sometimes absent littoral zone (essential for many limnological functions) that lacks a drainage basin. They are commonly associated with water of a poor quality containing high sulphate and metal concentrations and either very low or high pH values.

With only crude estimates regarding the actual number of these water bodies, they are typically associated with open cast mining (predominantly coal) and came about prior to the introduction of reclamation legislation in South Africa. Consequently the bulk of pit lakes are considered ownerless and hence part of the country's mining legacy problem.

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Fortunately many of these pit lakes are quite old and the possibility of these water bodies providing useful services cannot be excluded. However, given the extent of the pit lake restoration challenge and budgetary constraints from government and mining companies, a need arise to identify pit lakes worthy of restoration. Here, the term "worthy" might be interpreted from various perspectives and although a multi-disciplinary decision, monetary valuation of the expected benefits to society remains an important consideration as to decide whether or not to invest in the restoration of a particular pit lake. With no method currently available to compare and rank pit lakes in a consistent way and with legislation now demanding such restoration, a rapid assessment protocol for screening and ranking these water bodies is required to support decision-making in this regard. This work is considered a first attempt towards creating a standardised way (protocol) of assessing the current state of pit lakes paired to a monetary valuation of services to be expected from such water bodies which is then used for comparative purposes. The tool should be used to identify those pit-lakes worthy of restoration.

We make use of a pit lake index (PLI) to determine the ecological status of pit lakes. The index is based on appearances and measures of ecological processes of the pit lake including surface morphology, hydro-chemical characteristics, biological communities and external environmental and anthropogenic stressors. The index makes use of selected pit lake characteristics of type, landform, size and buffer zone. We explain the protocol that was used to first assess the eco-status of a pit lake where after a categorical score was allocated to the pit lake. This information is used to categorise the anticipated extent to which these water bodies can provide services. The categorical scores were then fed into a model to derive estimates of the monetary value to be expected from services of the specific pit lake in question. We illustrate the tool by means of a South African case study and conclude with a discussion of the potential application and current limitations of the tool.

2. Assessment protocol to determine the eco-status of pit lakes

Blanchette and Lund (2016) present two reasons why pit lakes (also refered to as cut lakes) remains problematic. Firstly, they argue that widespread confusion regarding suitable use of these water bodies remains, mainly because of the absence of a standard protocol for deciding what to do with these water bodies. Secondly, the apparent lack of an integrated transdisciplinary approach for managing pit lakes stand in the way of effective restoration. We do not contest any of these as our work aims to feed into this wider debate on ways to increase the effective management of mining legacies such as pit lakes.

No standard protocol currently exists to assess the ecological integrity of pit lakes and this is a first attempt to apply an index which can be standardised to allow inter pit lake comparisons. The PLI contains several ecological, hydrological and geomorphological water body characteristics: (Table 1):

(a) Pit lake types – we employed a modified version of Kumar (2009) to classify pit lakes.
(b) slope determines the formation of littoral zones where sunlight penetrate to bottom sediment creating most productive zone in terms of habituating rooted and benthic plants and phytoplankton.
(c) Pit lake size – we used 1:50 000 maps to estimate the surface area of a pit lake, after which we applied the geomorphic scale of Semeniuk (1987) to categorise the water body
(d) Pit lake buffer zones – we applied Mitsch and Gosselink (2000) and Gerber et al. (2004) to determine the cross-section distance of pit lakes.
(e) Hydro-period – the amount of time a pit lake is filled with water depends on rainfall and evaporation loss, recharge and discharge characteristics, and shape of the pit lake (Semeniuk and Semeniuk, 1995).

We employed the chemical, physical and biological indicators of the above-mentioned characteristics, to evaluate the structural and functional properties of pit lakes. This information was subsequently used to establish the 'eco-status' of pit lakes. The indicators included:

(a) Bank stability – we applied Spencer (1998) to assess bank erosion
(b) Width of fringing vegetation strip – in the case of wetlands, the width of the vegetation fringe is based on visual estimates of the strip using at least four cross-section points of the water body (Castelle et al., 1994; Bren, 1993; Dallas et al., 1993). However, the side slope of pit lakes vary substantially; hence we rather used flood height to determine the width of the riparian vegetation strip. We considered a 5 m wide strip as minimal protection to maintain aquatic functionality, whilst a strip greater than 20 m was considered to provide good protection to maintain aquatic functions (Barling and Moore, 1994; Macfarlane and Bredin, 2016).
(c) pH – was measured with a Hach sension TM 156 portable multiparameter (Loveland, USA). pH intervals were derived from changes in biodiversity (Kalff, 2001) where measurements below 6 and greater than 8 were considered as the thresholds for a drop in biodiversity.
(d) Electrical conductivity - strongly relates to the diversity and abundance of freshwater plants (Gómez Mercado et al., 2012). We employed Hillman (1986) and Crabb (1997) to define the conductivity range.
(e) Turbidity – we measured turbidity with a Hach 2100P Turbidimeter (Loveland, USA).
(f) Bottom sediment – we sampled with a sediment corer to a depth of 10 cm to analyse the extent of dissolved organic matter in bottom sediment.
(g) Dissolved oxygen – we categorized dissolved oxygen concentrations according to Alabaster and Lloyd (1982).
(h) Aquatic vegetation cover – we applied Pressey (1987) and Mitchell (1990) to determine the percentage of the water surface been covered with aquatic vegetation. We note that a pit lake which is completely covered with aquatic vegetation, may be due to nutrient enrichment and were allocated a low(er) score, whereas vegetation cover of 51–85 percent was allocated the highest score.
(i) Near surface suspended chlorophyll-a was used as an indicator of pit lake primary production according to Kalff (2001). Suspended chlorophyll a was measured in the field using a OTT Hydrolab DS5 multiparameter water quality probe. The categories used to establish productivity potential for the index were as follows: 1) >25 = hypertrophic; 2) 9–25 = eutrophic; 3) 3.5–9 = mesotrophic; and 4) <3.5 = oligotrophic. Measurements were collected in triplicate at each sampling site. We used a Van Dorn sampler (1 L) to collect planktonic algae at the surface and 2 m below surface. These samples were pooled and assessed. We sedimented samples in an algae chamber and used an inverted microscope at 1250× magnification to analyse by means of the strip-count method (APHA 1992, Truter 1987; Wehr and Sheath 2003; Van Vuuren et al., 2006; Taylor et al., 2007).