Coal mine pitlakes in South Africa

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Abstract It is estimated that there are over 110 coal mine pitlakes in South Africa associated with active, closed and abandoned mines. The final pitlake water quality impacts on the long term mine closure options. Pitlakes evolution has been studied globally and are used as a mine closure option worldwide. Despite there being numerous coal mine pitlakes in South Africa there has been very little research to determine if pitlakes are a viable mine closure option. This paper discusses the preliminary results of a South African Water Research Commission (WRC) funded investigation of four different coal mine pitlakes from various coal basins in South Africa. The paper describes field investigations of the pitlakes, involving profiling and sampling. Chemical algal and bacteriological analysis for the profiling has confirmed that stratification does occur in the pitlakes. Additional work will be undertaken to quantify the pitlake water balances especially in pitlakes that are hydraulically connected to old mine workings. The research found that the sustainability of the pit lakes is a function of the previous mining method and the relative size of the pitlake in comparison to the disturbed area. The research will result in the development of a manual for optimization of South African coal mine pit lakes to ensure that they are a sustainable environmental option for closure.

Key words Pitlake, water quality, stratification,

Introduction

Coal mining in South Africa commenced in the mid 1800's and is still the primary source of energy for the country, with coal fired power stations producing more than 90% of the country's electricity demand. Coal mining will continue to supply the growing energy demands and export, leaving behind old coal mines waste, alterations to the landscape and in the case of open cast mining, pitlakes. There are well over 110 pitlakes in South Africa most being in the Mpumalanga and Natal Coal fields, where the majority of the historical mining occurred.

Pitlakes are typically formed when groundwater levels rebound in the final void of an open cast coal mine. Historically, the final voids in South African opencast mines were not backfilled in an attempt to manage the water in the mines. This has led to the historical mining landscape being littered with pitlakes of various sizes and depths. In general, pit lakes are perceived to be associated with poor water quality water and pose a risk of overflowing and discharging contaminated water into surrounding water resources. In some cases, pitlakes were found to have relatively good water quality in conditions of low pyrite and high carbonate availability and large inputs of organic or inorganic nutrients prevail.

Little work has been done on characteristics of coal mine pitlakes in South Africa and their impact on the surrounding groundwater and surface water systems, and this study attempts to address the shortfall. Historical and ongoing mining in the coal fields of Mpumalanga, Natal and the Waterberg has created a number of coal mine pit lakes which range in age, depth and area. This project funded by the South African Water Research Commission investigates and compares four existing pitlakes in the Mpumalanga, Natal and Waterberg coal fields that have different geological, geochemical and hydrogeological characteristics and thus, are expected to display different pit lake behaviour and water quality evolution.

The water quality in pit lakes is governed by three major controls which includes limnological and geochemical processes as well as the geology which all contribute to the hydrogeochemical characteristics of a pit lake. Of particular importance in this study was the investigation of limnological controls in the pit lakes and their impact on water quality and in-situ water chemistry over time. The limnological controls are grouped into processes which physically separate the water column into two or more horizontal layers due to chemical and/or temperature gradients, called stratification, and processes that vertically homogenise the water column by mixing. (Bowell, 2002).

The physical limnology of pit lakes can therefore be described by two conceptual models namely holomictic pit lakes and meromictic pit lakes. Holomictic pit lakes consists of two distinct layers – an upper oxygenised layer and a lower, oxygen depleted layer- separated by a transition layer characterised by steep thermal gradients, called the thermocline.

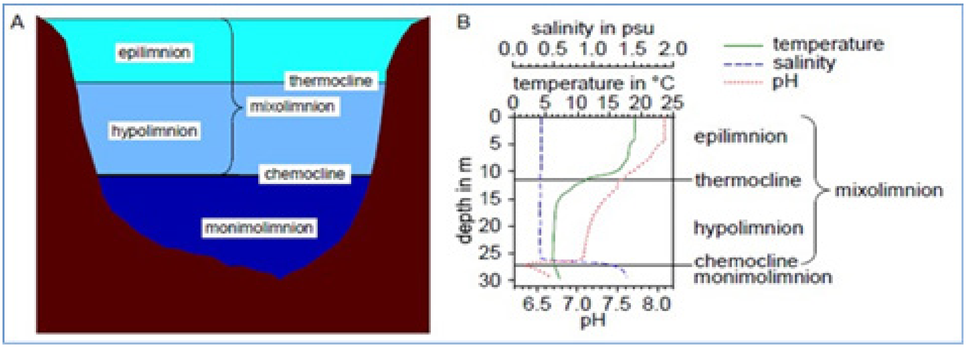


Figure 1 *Typical limnology of a Meromictic pitlake (Schultze et al. 2016)*

A Meromictic pit lakes comprise a third, chemically inactive layer at the bottom of the pit lake. When overturn occurs, this lowest layer does not participate in the mixing event and can be considered as a mechanism to concentrate contaminants at the bottom of the pit lake (Schultze et al. 2016).

In general, pit lakes are geologically young, artificial and geochemically complex systems which reflect permanent modifications to hydrologic systems and usually display poor water quality affected by poor quality leachate and in some cases acid mine drainage. The final lake surface levels represent the greatest risk of pitlake closure to stakeholders due to potential overflow and discharge of poor quality water to regional surface water bodies and groundwater resources.

In South Africa, there are a number of typical pit lakes which can be classed into three types according to the mining method and the final pit lake which will in turn determine its hydrological behaviour and chemical evolution. These are:

- Terminal pit lakes which are a result of a single excavation,
- Pit lakes associated with the final void of opencast operations that has partially been backfilled and rehabilitated,
- Pit lakes as a result of both underground and open cast operations where the open and underground mining operation are hydraulically connected.

Terminal pit lakes act as a hydrological sink and the only outflow from these pit lakes is by means of evaporation with the consequence of evapo-concentration of chemical components in the lake. Pit lakes associated with final voids of opencast operations where concurrent rehabilitation took place receive water which interacts with opencast spoils prior to entering the pit lake and this may cause an in increase in the total dissolved solids in the lake, depending on chemical characterisation of backfill material. If the water level in the pit lake fluctuates to above the water table, water may move from the pit lake into the surrounding groundwater table and this process may reverse in South Africa where evaporation exceeds rainfall by a factor of 2. Pit lakes which resulted from underground operations and open cast mining of the shallow coal (<40m) receive water from the underground mines which may impact the overall water quality and chemistry profile of these pit lakes.

Study Areas

The study area selected are in the different coalfields of South Africa, namely Waterberg Pitlake A and Pitlake B&C in the Mpumalanga coalfields and Pitlake D.

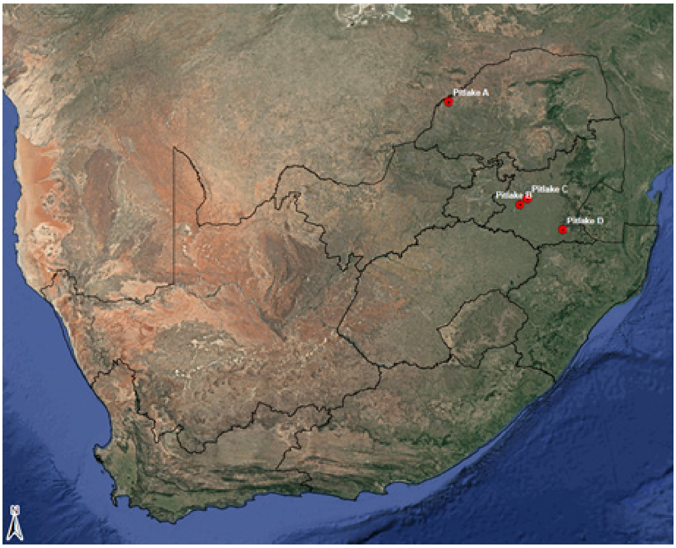


***Figure 2**: Map of South Africa with positions of pitlakes*

***Table 1**: Age, size, depth and volume of each pit lake with their respective coal fields.*

Pit lake	Coal Field	Age (years)	Max (m)
A	Waterberg	6	60
B	Highveld	20	20
C	Witbank	26	3
D	Natal	10	10

Pitlake A

Pit lake A is situated in the Waterberg coal field of South Africa. The area is characterised by an arid climate with high evapotranspiration of 2000 mm/a and annual average rainfall of 400 mm. Due to high temperatures in the summer months, significant evapo-concentration is expected. The pit lake formed in a void left by a single bulk excavation of coal to a depth of 96 m. Geologically, the area consists of Karoo Supergroup successions with the coal-bearing horizons consisting of the Upper and Middle Ecca group where 11 coal zones are present. Mining activities ceased in 2010 where after groundwater levels rebound to equilibrium levels and displayed stable conditions for at least six years. The pit is not connected to other mining operations and therefore acts as a stand-alone pitlake which receives water from limited surface run-off from the Greater Limpopo River Catchment area and groundwater inflow from the surrounding aquifer. At the time of investigation, the depth of the pit lake was 68 m.

***Figure3**: Pitlake A*

***Figure 4**: Aerial image of Pitlake A*

Pit Lake B

Pit lake B is located in the Mpumalanga. The opencast operation has been partially back-filled and rehabilitated, leaving a pit lake with a maximum depth of 20 m. The geology of the area consists of sandstones interbedded with siltstone, grit and mudstones which forms part of the Ecca group of the Karoo Super group. Although coal seam No 1 to 5 present at this colliery, coal is mainly extracted from coal seam No.4, which varies in thickness of 4.8 to 70 m (Hancox and Gotz 2014). The climate is temperate with a mean annual rainfall of approximately 711 mm and average evaporation of 1730 mm.

***Figure 5**: Pitlake B*

***Figure 6**: Arial Image of Pitlake B*

Pitlake C

Pit lake C is situated in Mpumalanga coal field. The opencast operations ended in 1991 after which the groundwater level was left to rebound to equilibrium levels. The roll-over mining method was employed where coal was extracted from the Vryheid formation of the Ecca Group of the main Karoo basin. The area consists of alternating sandstones and shales with coal seam No. 1 to 5 present (Hancox and Gotz 2014). The majority of this opencast operation has been backfilled and rehabilitated leaving a relatively narrow and elongated pit lake with a maximum depth of 3 m.

The climate is temperate with an average annual rainfall of 670 mm/a and potential evaporation of 1600 mm.

***Figure** 7: Pitlake C*

***Figure8**: Arial Image of Pit Lake C*

Pitlake D

Pit lake D is situated in the Natal coal field, where coal is extracted from the Alfred, Gus and Dundas seams. The mining operation comprised of an underground and opencast activities which commenced in 1997 and ceased in 2007. The opencast area is hydraulically connected to the underground mine and both are connected to the pitlake. The maximum depth is 10 m. The area receives high rainfall, mostly in the form of heavy thunderstorms. Mean annual rainfall is 700mm and potential evaporation of 1 700 mm.

Figure 9*: Pitlake D*

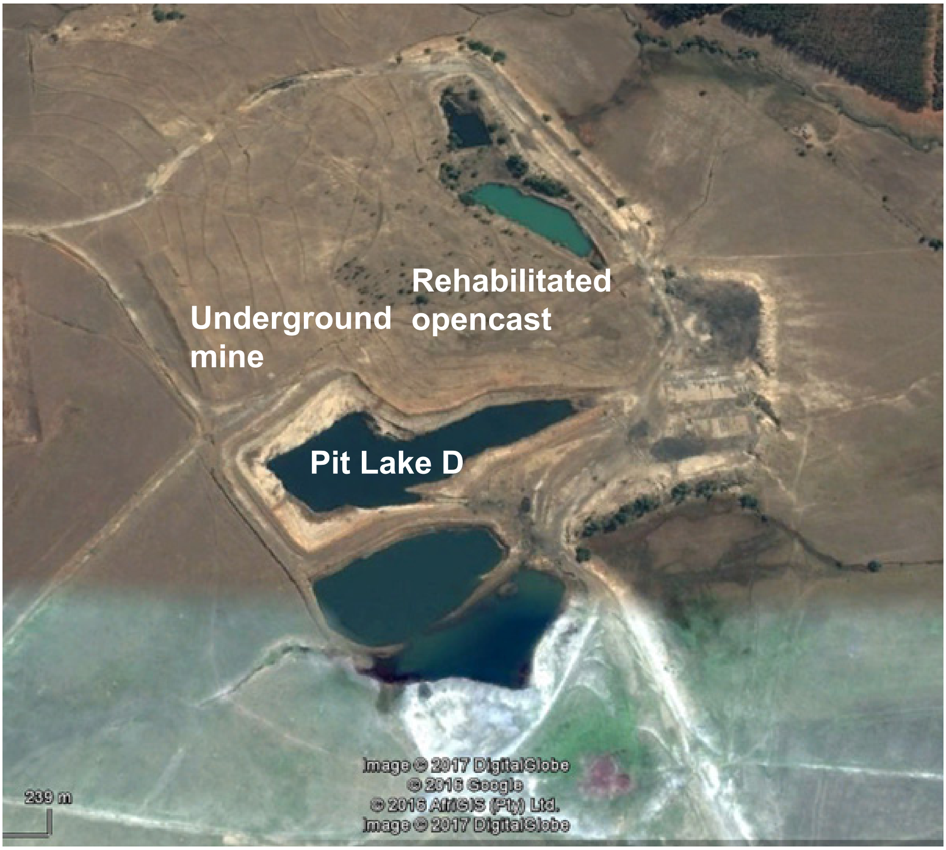


Figure 10*: Plan view of Pit Lake D indicating the underground portion and rehabilitated opencast area.*

Methodology

The field investigation involved four different study areas related to the respective conceptual models of pit lake types. The aim of the investigation was to determine the water quality and chemical signature of the pit lakes as well as possible stratification brought about by steep thermal or chemical gradients. The method of investigation comprised of multiparameter depth profiles with an YSI EXO (Yellow Springs Instruments) profiler and water sampling with a submersible pump connected to a 12 V energy source. Sampling depths were derived from the water quality profiles, whereby the position of the thermocline was used to distinguish the thickness of the epilimnion and hypolimnion to ensure sampling of both layers. Profiling and sampling were performed at the same position in the pit lake, typically the deepest point in the pit lake. Lateral homogeneity of the pit lake water quality was assumed. Chemistry, bacteriological and algal samples were sent for analysis. Unfortunately, at the time of this paper laboratory analysis was only received for Pit Lake A and D.

Results: Water Quality

Pit Lake A

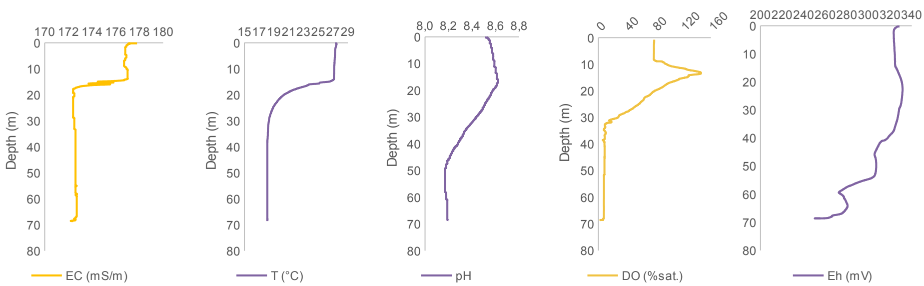


***Figure 11**: Water column profiles for Pit Lake A (Jan 2017).*

Pit Lake B

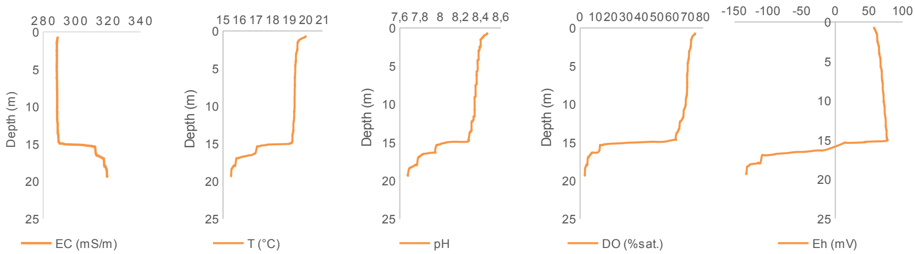


***Figure 12**: Water column profiles of Pit lake B (April 2017).*

Pit Lake C

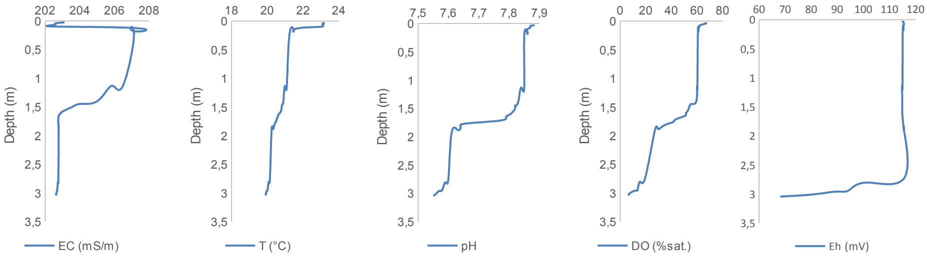


***Figure 13**: Water column profiles of Pit lake D (March 2017.)*

Pit Lake D

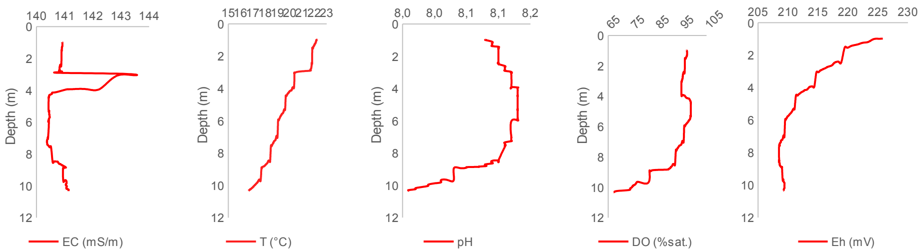
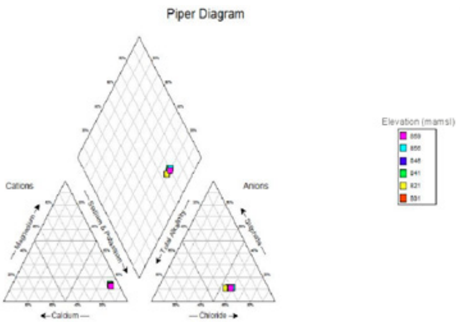


***Figure 14**: Water column profiles of Pit lake D (November 2016.)*

Water Quality Pitlakes A & D

At this stage only the water quality of pitlakes A and D is available which involves the inorganic chemistry, bacteriologic and algal analysis.



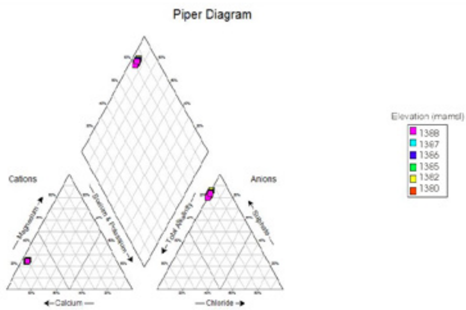


***Figure 15**: Water chemistry of Pitlake A.* ***Figure 16**: Water chemistry of Pitlake D.*

Pitlake A is a single bulk sample and not adjacent to any other workings. As a result the pitlake water balance comprises rainfall and groundwater inflow and the losses comprise only of evaporation. The electrical conductivity ranges from 176 on surface to 172 mS/cm at 60 m. The water is a sodium chloride water with Na of 260 mg/L and Cl 348 mg/L, with SO4 concentrations of 108mg/L. The surrounding aquifer water quality is also sodium chloride in nature with Na 200mg/L, Cl 295mg/L and surprisingly low SO4 of less than 10mg/L . The metal content is very low due to the relatively alkaline pH

Pitlake D is linked to both opencast and underground workings. The EC is 133 mS/m and the water is largely a calcium carbonate in character with Ca 240mg/L, SO4 600, and very low Cl 2mg/L and Na 16mg/L .The metal content is very low due to the relatively alkaline pH

Discussion

The water quality in the four pitlakes investigated are markedly different with variations in the stratification and in the overall pit water quality. All samples were taken in the summer months.

Table 2*: Pitlake Water Quality*

	EC mS/m	T C	pH	DO %Sat	Eh Mv	Depth of Thermocline	Depth of Pit Lake
Pit A	176	27	8,5	80	325	13,93	68,55
Pit B	290	20	8,5	80	80	14,91	19,25
Pit C	200	23	7,9	70	125	1	3
Pit D	141	23	8,1	100	230	2,85	10,1

Electrical Conductivity: The EC varied from 176 to 290 mS/cm (TDS 1126 to 1856 mg/L) and in general the poorer water quality on surface except in the case of Pitlake B. Pit Lake B is an opencast operation and the reasons for the lower poorer quality is not clear.

Temperature: In all cases the top of the pit lakes was warmer than the lower portions of the pitlake. This can be expected as the sampling was undertaken in the summer months. The thermoclines varied between 13.93 below surface for the deep pitlakes to 1 m for the very shallow lakes.

pH: In all cases the pH of the pitlakes were alkaline on surface and did not vary significantly with depth indicating that the pitlakes are alkaline and as a result did not show a major influences of acid mine drainage if either of the lakes.

Dissolved Oxygen: Dissolved oxygen as expected decreased with depth. This is typical of a pitlake and as a result will impact on the biota with a general increase in the algal, invertebrate and vertebrate species in the upper levels of the pitlakes.

Eh: the redox potential of all the pit lakes is positive except the lower portion of pitlake B which is negative

Bacteriological Analysis: Water samples analysed were taken from all pitlakes for microbial diversity. Result have only been received from pitlake D. The analysis involved using denaturing gradient gel electrophoresis (DGGE) fingerprinting method. Initial identification of possible micro-organisms present through sequence analysis elucidates possible environmental condition(s). The DGGE fingerprinting revealed possible diverse bacterial population in the samples. PDP6-2M (Pit Lake D profile 6 at 2m) and PDP6-3.5M have similar DGGE fingerprinting with possible dominant phylotypes. Samples PDP3-2M, PDP3-6M, and PDP3-14M also possess similar DGGE fingerprinting. However, sequence analyses will reveal the identity of bacteria present in the samples.

Algal Sampling

Only results have been received for Pitlake A. The planktonic chlorophyll algal concentration was determined by lowering a secchi disc (0.2 m diameter) and subsequently obtaining the secchi depth. Sampling was performed to a maximum depth of three times the secchi depth. The secchi depth was determined as 7 m in Pitlake A and samples were collected at 0.5 m, 1 m, 7 m and 20 m.

- Sample 1.2- 0.5 m depth = 3 μg/L
- Sample 1.3- 1m depth = 6 μg/L
- Sample 1.8- 7 m depth = 3 μg/L
- Sample 1.7- 20 m depth = <1 μg/L

According to the results given, it can be seen that the pit lake is mainly oligotrohic with the highest concentration of chlorophyll-a occurring at approximately 1 m below the surface of the water.

Water Balance

In all the pitlakes investigated there is negative water balance when comparing rainfall and evaporation. There is not a major change in the pitlake levels between seasons due to other sources of recharge to the pitlake. In the case of pitlake A the inflow of groundwater from the surrounding aquifer pays a significant role in maintaining the pitlake level. In the other pitlake B, C & D which are connected historical mine workings here is additional flow from the old mine workings into the pitlake. Additional work will be undertaken to quantify the pitlake water balance.

Conclusion

The Project is still in its infancy and a lot of the data must still be analysed. There are however some interesting results from the four pitlakes. Additional work will involve chemical bacteriological and algal analysis. All pitlakes will water balances will be modelled to determine sources and sinks.

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