

The Influence of a Graben Structure on Pollution Migration from Mining and Industrial Waste Facilities

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Abstract

Graben structures can influence both the direction and rate of groundwater flow and the migration of pollutants. The investigation aimed to determine the pollution distribution along a graben structure that extends through a mining and industrial facility. The investigation involved a desktop review of existing data, geophysical surveys, and collection of field data through drilling of analytical boreholes, complimented by aquifer tests, down-the-hole chemical profiling, and isotope analysis. The investigation indicated that the faults associated with the graben structure act as conduits for the migration of pollutants from the different waste facilities towards local river valleys.

Keywords: Graben, faults, pollution migration, industrial, waste facility

Introduction

Large-scale geological structures such as graben structures can influence both the direction and rate of groundwater flow and the migration of pollutants. Graben structures can act as preferred pathways for groundwater flow and pollution migration, or they can act as a barrier, depending on the specific characteristics of the structure and the associated lithology (geological material).

Aim and Objectives

The aim of the investigation was to determine the pollution distribution along a graben structure that extends through a mining (coal) and industrial facility (Fig. 1) The objectives of the investigation were 1) develop a conceptual understanding (model) of the geology and geohydrological processes along the graben (fault) system, 2) identify the main sources of pollution, 3) identify the distribution and/or movement of pollutants and associated risk, and 4) propose mitigation and management measures to limit/reduce pollution migration.

Materials and Methods

The methodology of the investigation was structured into three phases.

Phase 1

The initial phase involved a desktop review of existing data to identify information gaps. The desktop review was supplemented by a geophysical investigation along the graben structure to identify conductive zones and site additional analytical boreholes to address data gaps and enhance the understanding of the geological and hydrogeological characteristics of the area. The geophysical methods applied included the Electromagnetic (EM) method using a Geonics EM34-3 and the Electrical Resistivity Tomography (ERT) method using an ABEM SAS 1000.

Phase 2

Phase 2 involved the collection of primary field data through the drilling of analytical boreholes, complemented by a series of aquifer tests, down-the-hole chemical profiling, and isotope analysis. The data was used to develop a conceptual model of the groundwater system, outlining the key processes and interactions within the groundwater system and how the graben structure influences the pollution migration from the different waste facilities.

A total of 28 analytical boreholes were drilled using the air-percussion method. The boreholes drilled consisted of 13 shallow (15



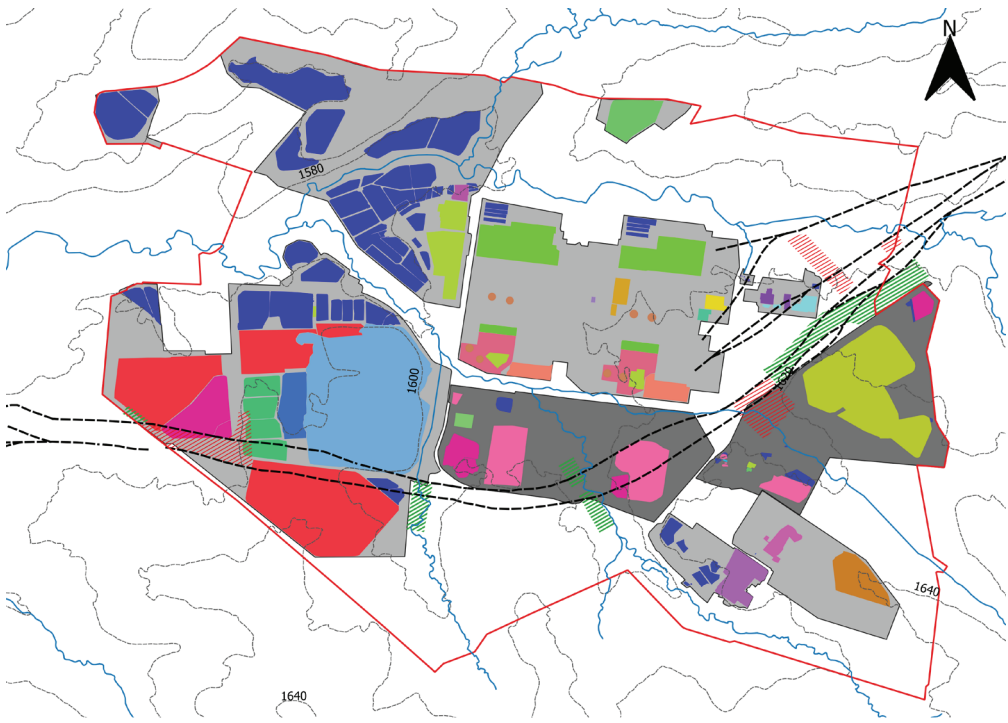
m) boreholes targeting the weathered aquifer and 15 deep (40 m) boreholes targeting the mapped graben structure and associated faults (fractured aquifer).

Aquifer tests included slug tests and constant rate discharge tests. Slug tests were performed on all the boreholes to estimate initial hydraulic properties and to identify boreholes for constant rate discharge tests. Five boreholes were identified to be suitable for constant rate discharge tests to calculate hydraulic properties more accurately.

Down-the-hole chemical profiling was conducted on all the analytic boreholes

with a YSI 600XLM Multi-Parameter Probe (calibration before deployment was done with the appropriate standard solutions). This allowed for the in-situ measurement of multiple parameters which included temperature, dissolved oxygen (DO), oxygen reduction potential (ORP), pH, and electrical conductivity, enabling the identification of fracture zones within the boreholes.

Water samples were collected from all the analytical boreholes, existing monitoring boreholes, and surface water sources (potential pollution sources). The samples collected were analysed for physical- and



LEGEND

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|------------------------------|---------------------------------|-----------------------|-----------------------------|
| Study Area Boundary | Industrial Facility | | |
| Rivers/Stream | Mining Facility | | |
| Elevation Isolines (20 m) | | | |
| Geological Structures | | | |
| Graben and Associated Faults | | | |
| Infrastructure | | | |
| Coal Bunker | Cyanide Plant | Fine Ash Dam | Old Black Products |
| Coal Discard Dump | Detergent Alcohol Plant | Fine Coal Dam | Polymer Plants |
| Coal Preparation Plant | Domestic Waste Dump | Fuel Filling Station | Polymer Warehouses |
| Coal Processing Plant | Effluent Dam | Fuel Filling Stations | Power Station |
| Coal Stock Piles | Ethyl Acetate Plant | Magazines | Power Station Cooling Tower |
| Coarse Ash Dump | Explosive Manufacturing Plants | Mine Water Dam | Reclamation Yard |
| | Fertilizer Manufacturing Plants | | Sewerage Plant |
| | | | Solvents Plant |
| | | | Sulphur Plant |
| | | | Tank Farms |
| | | | Water Works |

Figure 1 Study area layout map indicating the position of the graben and associated faults.



inorganic parameters, and stable isotopes (oxygen & hydrogen). The samples were collected using a stainless-steel specific depth sampler (bailer) at predetermined depths (flow fracture/flow zones).

Phase 3

Phase 3 synthesised all the findings to identify critical pathways for pollution movement from the various pollution sources. Identify areas of risk and recommend possible management and/or mitigation measures.

Site Description

Climat

Climate data from the South African Weather Services weather station 0478330 3 is available from 1984 to 2018. Over this period, the mean annual rainfall is 758 mm, mainly occurring in the summer months of October to March in the form of thunderstorms. It receives the highest mean rainfall in January (148 mm) and the lowest mean rainfall in the July (4 mm). The mean maximum temperature varies from 18 °C in the winter to 27 °C in

the summer, whereas the mean minimum temperature varies from 1 °C in the winter to 14 °C in the summer.

Topography and Drainage

The topography of the study site forms a high of 1639 mamsl in the southeast to a low of approximately 1568 mamsl in the west of the site. The site is drained by three non-perennial streams, that enters the site from the northern and eastern boundaries and. Drainage from the north and east is expected to follow the topography towards non-perennial streams (Fig.1).

Local Geology

The geology underlying the study area mainly comprises sedimentary rocks of the Vryheid Formation that were intruded during the Jurassic period (200 to 145 Ma) by numerous interconnected dolerite saucers (sills) and dykes (Fig. 2 and Fig. 3) which frequently transgress and displace the stratigraphy (Coetzee 2016). The Vryheid Formation is assigned to the Ecca Group within the Karoo

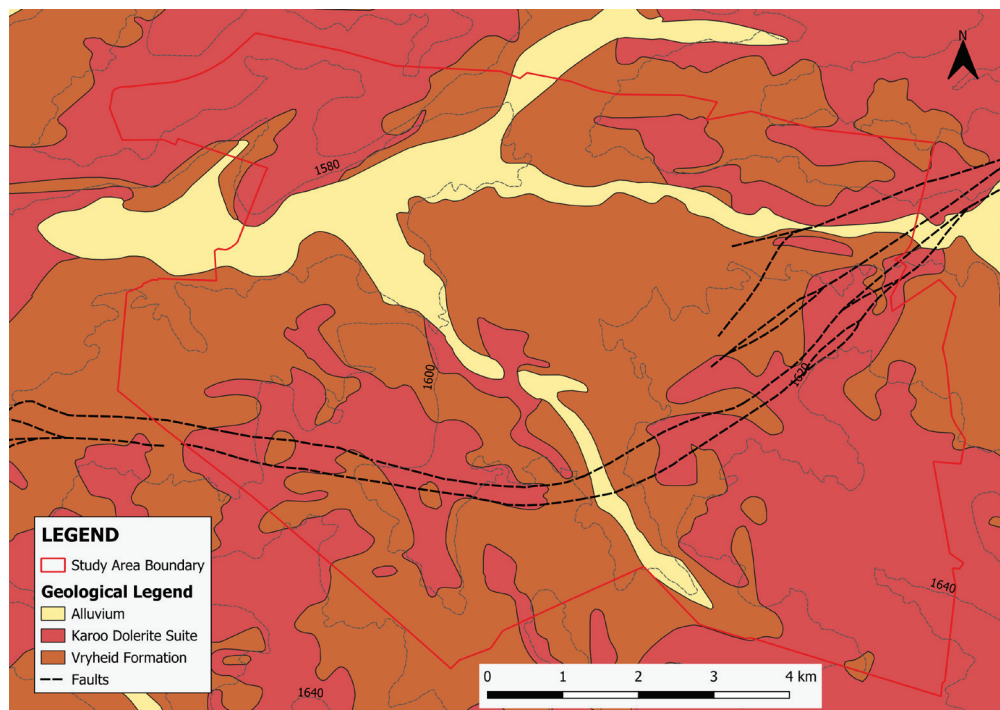


Figure 2 Study area geological map.



Supergroup. According to Johnson *et al.* (2006) the Vryheid Formation was deposited within three different environmental environments which includes a lower fluvial-dominated deltaic environment, a middle fluvial environment and an upper fluvial-dominated deltaic environment and is the host formation for the majority of South Africa’s economic coal reserves (Cairncross and Cadle 1987).

Hydrogeology

The geohydrological system associated with the Vryheid Formation of the Highveld Coalfield consists of two distinct and

superimposed aquifers, as described by Hodgson and Krantz (1998). They are the upper/shallow weathered aquifer and the deeper fractured rock aquifer.

The shallow weathered aquifer is associated with the weathered horizon which consists of soil and weathered rock. The depth of weathering generally ranges between five (5) and 15 metres below ground level (mbgl) and water is often intersected within a few metres below surface (Hodgson and Krantz 1998; Vermeulen and Usher 2006). The aquifer is recharged by rainfall and the recharge percentage is in the range of one to three percent of the annual rainfall (Hodgson and Krantz 1998).

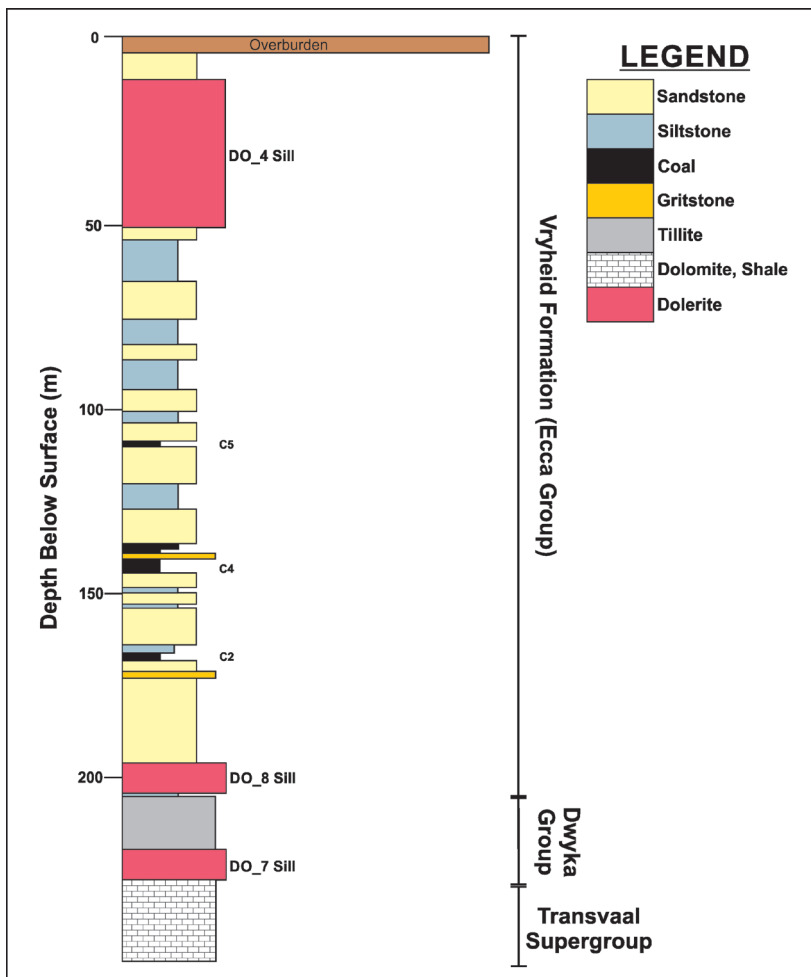


Figure 3 Generalised stratigraphic column for the Highveld Coalfield of the study area (Modified from source: Coetzee and Kisters, 2016).

Studies conducted by Menghistu (2010) and a geophysical survey across the graben at the mining and industrial facility indicated that the area along the graben and associated faults are underlain by a highly weathered and fractured dolerite sill. The shallow weathered aquifer could be prone to pollution from potential surface sources if leachate from these sources seeps into the subsurface via fractures and interconnected pores. The upper fractured aquifer is also likely to be affected by groundwater pollution if groundwater moves vertically along fractures, fissures and cracks and possible fault planes along the graben. The deeper lying alternating layers of sandstone, shale and siltstone are of lesser concern as the shale and siltstone layers are nearly impermeable to water movement and form a no-flow boundary (Hodgson and Krantz, 1998). Therefore, these layers can prevent pollution plumes from migrating into deeper geological strata.

Results and Discussion

The interpretation of available information indicates that at some locations along the

graben structure did not contain enough information to determine groundwater flow directions within/along the graben. The following flow direction could be identified: 1) at the Coarse Ash Dump the general flow direction is north towards the local streams, 2) at the Coal Stockpiles, Effluent Dams (fertiliser) and mine water dam at the eastern coal stock pile, the general flow direction is northwest, and 3) at the eastern section (near the Coal Discard Dump), the flow direction is north.

Fig.4 displays zones of high conductivity that were identified by the geophysical survey. The resistivity survey, at some locations, could clearly identify the graben and the associated faults by a distinct change in resistivity in areas where the graben structure was often composed of less resistive material. Some of the zones of high conductivity are not confined to the graben but probably related to the shallow weathered aquifer and local dolerites sills that act as barriers to form perched aquifers that creates wetland at places.

The estimated transmissivity for the matrix was on average 0.17 m²/d and

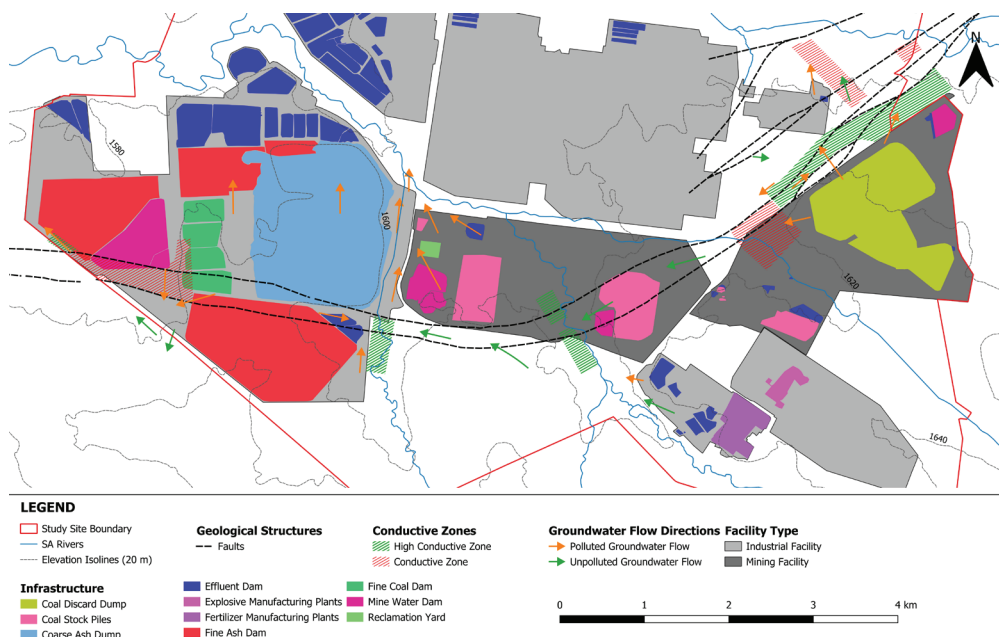


Figure 4 Study area layout map indicating the conductive zones and groundwater flow directions along the graben structure.



2 m²/d in the fracture network within the valleys in the west, and pollutants in the graben (weathered zone), whilst the pollutants located in the eastern section flow towards boreholes, targeting the fault zone, indicated by the local rivers in the east.

an average transmissivity of 1.9 m²/d and 123 m²/d for the matrix and fracture network, respectively. The constant rate discharge tests estimated the transmissivity to range between 0.2 m²/d to 3.7 m²/d with an average of 0.67 m²/d. To Re-evaluate the depth of existing cut-off trenches as well as the location of existing sumps and pumping rates from these

The transmissivity along the fractures may vary greatly, depending on the fracture network as well as its size and extent. The

Investigate the base-flow of the Coal similar transmissivity values calculated Discard Dump during wet and dry during the constant rate discharge tests seasons to evaluate the seepage via indicates that groundwater flow is from unlined sidewalls into the subsurface the matrix and fracture system and it is not and based on the results, design and possible to distinguish between the two implement mitigation measures.

Therefore, groundwater flow occurs along a zone and not a single fracture. unlined sections of the different waste

The interpretation of the existing data together with the data collected during

phase 2 of the investigation, identified and

of surface and groundwater pollution, and the identification of the groundwater flow paths (polluted and unpolluted) (see Fig. 4). These findings indicates that pollution from the Coarse Ash Dump and Fine Ash Dams only affects the western area of the graben, whilst it does not affect the eastern area of the graben. The groundwater pollution from the Coal Stockpiles and the Fertiliser Effluent Dams do not affect the pollution in the eastern area of the graben as flow at these sites varies from west to northwest. The groundwater pollution from the Coal Discard

Dump effects the western area of the graben. Water level data, down-the-hole electrical conductivity profile data, and chemistry data suggest that groundwater flow and pollution migration occur across the graben and along the strike of the associated faults.

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Proposed Management/Mitigation Measures (Recommendations)

The following management and/or mitigation measures are recommended

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Conclusions

The investigation indicated that the faults associated with the graben structure act as conduits for the migration of pollutants from the different waste facilities. The groundwater flow direction within the graben structure is governed by the prevailing groundwater flow system, where pollutants in the western section of the graben flow toward the local