Hydrogeochemical impacts of the Gaborone landfill on its surrounding subsurface environments

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Abstract

A hyrogeochemical study is currently being undertaken to assess the impact of the Gaborone landfill on its surrounding surface and subsurface water resources. Soil and granitic saprolite were analysed for their minerals content. Surface and subsurface water samples were analysed for water quality indicators, dissolved inorganic carbon (DIC) concentration and δ¹³C DIC. Geophysical investigations employing electromagnetic and electrical resistivity techniques were conducted in order to delineate the presence of any leachate emanating from the landfill. There are observed changes in water chemistry in the environment, which could be accounted for by the weathering of aquifer minerals being enhanced by carbonic and organic acids presumably from the landfill and sewage ponds. Moreover, two major contaminant plumes were identified as well as several smaller ones. Further research is needed to fully characterise the plumes in order to assess the landfill’s full impact on the environment.

Introduction

This is an informative article on an on-going research, which focuses on the interaction of the Gaborone landfill with its immediate subsurface environment. The presently operating Gaborone landfill was constructed in 1993 to replace the old dumpsite, which was due for closure. In 1995 the abandoned dumpsite was rehabilitated through an initiative of Somarelang Tikologo by topping with soil and grass planting. However, environmental impact assessment (EIA) studies carried out prior to the commissioning of the present landfill revealed that it should be sited elsewhere, not at its current location (Arup, 1993).

Poorly managed landfills are known to cause environmental degradation, for instance through release of leachate and gaseous contaminants into the surrounding. It is unfortunate that both the decommissioned dumpsite and the present landfill are not being monitored accordingly, and that their location does not suit recommended siting of landfills.

Geographical location and background

The Gaborone landfill is located east of Gaborone City behind the Trade Fair Grounds. It measures 630m N to S and 340m E to W. The site is fenced, and has four monitoring boreholes which serve in accessing samples for groundwater quality, but are rarely employed. The subsurface geology at the site consists of soil and saprolite weathered from the Kgale Granite of the Gaborone Granite Complex, and the average depth to water table is 4m. The surface water consists of the Gaborone impoundment feeding the Notwane River which flows to the north-east. Groundwater flow is presumed to be towards the Notwane River based on the surrounding topography. The Gaborone landfill, being upstream and slightly elevated from the Notwane River, has a potential

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of polluting this channel and any aquifers which get recharge from the river. Notwane River feeds Gaborone dam, thus its flows are greatly reduced at the downstream end. The study area is located below the dam.

Aims and objectives of the study

This on-going study aims to achieve the following objectives:
• Assess soil and water quality in the monitoring wells at the landfill and along Notwane River up to Odi village.
• Characterisation of the soil mineralogy along the river.
• Assess the extent of contamination in surface water, subsurface soil and subsurface water.
• Establish whether there is a relationship between contaminants in the dumpsite and the surrounding subsurface environment.
• Suggest mitigation steps to alleviate any complications associated with contamination.
• Make recommendations to the responsible bodies about the findings of the study.

Some of the objectives have been realised; and are subsequently reported in this paper.

Methods and analytical techniques

Sampling
Grab water samples were collected from segments of the Notwane River and from standing water at the landfill site, while groundwater was sampled from three bore holes at the landfill site. Aquifer solids were sampled by collecting soil samples at the surface and granitic saprolite at a depth of 1.5m below the surface.

Instrumentation and analytical techniques
Water samples were analysed for water quality indicators (electrical conductivity (EC), hardness, biological oxygen demand (BOD), chemical oxygen demand (COD)), major cations (Na\(^+\), K\(^+\), Ca\(^{2+}\), Mg\(^{2+}\)) and anions (HCO\(_3^-\); CO\(_3^{2-}\); Cl\(^-\); SO\(_4^{2-}\); F\(^-\)), using the techniques mentioned in Geeberg et al (1992), dissolved inorganic carbon (DIC) concentration, and $^{13}$C\(_{DIC}\). X-Ray Powder Diffraction (XRPD), of which the technique is described in Ekoesse and Vink (1999), was used to obtain the mineralogical composition of the aquifer solids. Geophysical investigations were conducted at the landfill site in order to delineate the presence of any leachate emanating from the landfill. Electromagnetic and electrical resistivity surveys are geophysical instrumentation techniques employed in the study, and the methods are described in Kayabali et al (1998).

Results and interpretation

Aquifer mineralogy
The granitic saprolite consists of hornblende, plagioclase, microcline, muscovite and quartz in major and minor quantities (Figure 1). The soil consists of microcline, muscovite, quartz, smectite and kaolinite (Figure 2). The weathering of aquifer minerals (plagioclase, K-feldspar and muscovite from the granitic saprolite and soil may account for the major ion chemistry and water evolution.
Figure 1:  X-ray diffractogram of granitic saprolite sample indicating major and minor mineral phases present in the sample

Figure 2:  X-ray diffractogram of soil sample indicating major and minor mineral phases present in the sample
Surface and subsurface water chemistry
The changes in water quality, major ion chemistry and δ¹³C DIC suggest input of water with a different water quality along this segment of the Notwane River. Changes in water chemistry along the Notwane River can be accounted for by the interaction of surface water, groundwater and surface disposal facilities such as the landfill and sewage ponds.

General patterns in the ion chemistry show very high electrical conductivity, total dissolved solids, nitrates, and chloride content among others at two of the bore holes (Bore holes 3 and 1) exceeding the acceptable drinking water standards. These wells also show very high levels of BOD and COD suggesting landfill contribution. Weathering of aquifer minerals (plagioclase, potassium feldspars and muscovite) from the soil and granitic saprolite can account for the major ion chemistry and water evolution.

Trends in water quality parameters and major ion chemistry change along Notwane River. The DIC concentration decreases down-gradient along the stream, as well as the δ¹³C DIC. The DIC/δ¹³C DIC data suggest impounded water recharge; normal groundwater evolution and surface disposal facilities play a role in the site hydrology and hydrochemistry.

Geophysics
Results from geophysical studies (electromagnetic and electrical resistivity surveys) suggest the presence of two major plumes (Figure 3 and Figure 4). The first plume appears to be emanating from

Figure 3: In-phase and quadrature component response along a transect. Peaks define location of contaminant plumes.
Figure 4: Electrical resistivity response along a transect. Peaks define location of contaminant plumes.

from the vicinity of BH3 heading towards the Notwane River. The second plume is suggested to be emanating from Borehole 1 moving in a direction towards the dam. The geophysical studies also suggest the presence of several other smaller plumes emanating from sources northwest of the landfill (between the landfill and Water Utilities).

Recommendations

To assess the full impact of the landfill to the groundwater quality in its vicinity necessitates further work. This work could benefit from an assessment of stream discharge, seepage flux and seepage chemistry along the Notwane River. A recommendation is also made to increase the number of background surface and subsurface water sampling locations.

Additional boreholes should be emplaced within the plumes delineated by the geophysical studies as well as off plume areas. Water quality and carbon isotopic analyses from the bore holes, streams, and dam should be carried out in order to evaluate ground water, dam water and stream water interactions. Furthermore, additional geophysical studies should be conducted. This is crucial for plume characterisation (both lateral and vertical) and necessary for the judicious placement of monitoring bore holes in order to reduce costs.
Conclusion

Changes in water chemistry along the Notwane River can be accounted for by the interaction of surface water, groundwater and surface disposal facilities (landfill and sewage ponds). The DIC/δ¹³C$_{DIC}$ data suggest that impounded water recharge, normal groundwater evolution and surface disposal facilities play a major role in the landfill site hydrogeochemistry. The need for further detailed research to fully characterise the trends of the subsurface hydrogeochemistry and to come up with very specific findings/recommendations can not be over-emphasised.

Acknowledgments

The Department of Water Affairs assisted with water quality analyses. Mineralogical analyses were carried out at the X-ray diffraction laboratory of the Faculty of Science, University of Botswana. DIC concentration and δ¹³C$_{DIC}$ were performed at the Western Michigan University, Kalamazoo, USA and the Indiana University Purdue University, Indianapolis, USA. We would also like to thank the Gaborone City Council and in particular Mr Dipite for all the collaboration given to us in accessing information about the landfill and obtaining samples for laboratory analyses.

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