

# Assessment of groundwater pollution vulnerability and modelling of the Kanye Wellfield in SE Botswana—a GIS approach

B.F. Alemaw \*, E.M. Shemang, T.R. Chaoka

*Department of Geology, University of Botswana, P.O. Box 0022, Gaborone, Botswana*

---

## Abstract

Botswana is a semi-arid country with limited recharge to groundwater resources. Groundwater however is a major source of water for domestic, industrial and agricultural uses. There is therefore the need to ensure that the groundwater resources are of drinking quality, by protecting them against pollution sources such as landfills, pit latrines, industries, agricultural pesticides and waste. In this study a preliminary assessment of vulnerability of groundwater to pollution in Kanye well field in SE Botswana is undertaken. In order to assess the vulnerability of this aquifer to pollution, soils types, mapped geology and information from 82 boreholes were input into a GIS system to classify pollution vulnerability using Theissen polygons of the study area. Results indicate that 58% of the well field area is highly or very highly vulnerable to pollution, 34% is moderately vulnerable to pollution, and only 9% has low vulnerability. Estimates of the aquifer media characteristics in areas with only a few observations or few geological logs were considered to have higher uncertainty than areas with many observations. However, the use of the polynomial estimator enabled consideration of simple uncertainty for the aquifer media characteristics and pollution vulnerability modelling process.

© 2004 Elsevier Ltd. All rights reserved.

---

## 1. Introduction

As a semi-arid country, Botswana has little recharge to groundwater resources. Studies have shown that groundwater replenishment rate is very low (Beekman et al., 1996). Groundwater however is a major source of water for domestic, industrial and agricultural uses. There is therefore the urgent need to ensure that the groundwater resources are of drinking quality, by protecting them against pollution sources such as landfills, pit latrines, industries, agricultural pesticides and waste.

Groundwater contamination is a major concern in Botswana. Two wellfields, the Ramotswa and the Mochudi wellfields in the southeastern part of Botswana are no longer used for drinking purposes as a result of bacterial and nitrate pollutions caused by poor disposal

sanitary waste (Department of Water Affairs, 1993). Other wellfields are showing evidence of similar pollution. These include the Molepolole wellfield in the central part of the country and the Serowe and Palapye wellfields in the northeast.

The vulnerability potential of an aquifer to pollution depends to a large extent on the susceptibility of its recharge area, as areas with high replenishment rate are potentially more vulnerable to pollution than others (Bekesi and McConchie, 2002). Unconfined aquifers that do not have a cover of impermeable material are also susceptible to contamination. Soils overlying the water table provide the primary protection against ground water pollution.

## 2. The study area

The present study was undertaken on the Kanye wellfield (located between longitudes 25°–25.4°E and

---

\* Corresponding author.

E-mail address: alemaw@mopipi.ub.bw (B.F. Alemaw).

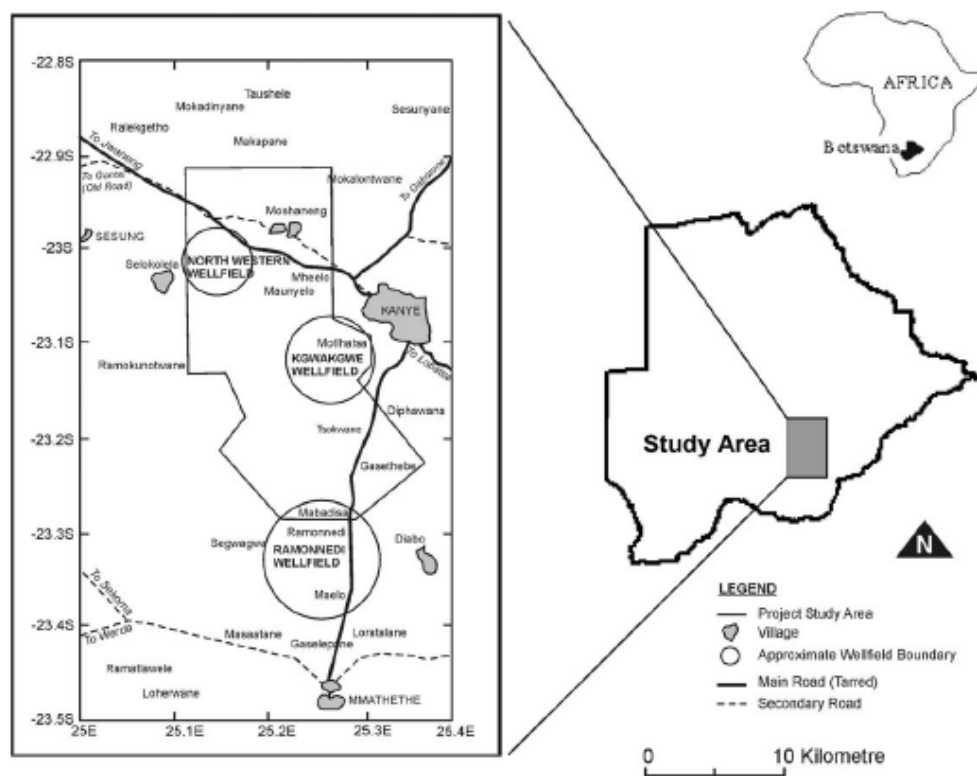


Fig. 1. Kanye Wellfield location map.

latitudes  $24.8^{\circ}$ – $25.5^{\circ}$ S Fig. 1), south-eastern Botswana with the aim of assessing the vulnerability of this well field to pollution. The Kanye wellfield comprises three sub-areas where groundwater is abstracted by the Water Utilities Corporation: Northwest, Kgankgwe and Ramonnedi. The main potential source of pollution of this well field is agricultural activities (mainly livestock farming) and domestic waste disposal.

The aquifers in the Kanye wellfield consist essentially of carbonate rocks (dolomites) that are highly fractured and fissured at some places. Karst phenomenon is also prevalent within these aquifers.

### 3. Methodology

In order to assess the vulnerability of this aquifer to pollution, the types of soils overlying the area were divided into 3 classes, based on their ability to permit flow of fluids. Class one included very coarse-grained soils (sands, gravels, dolomites and calcretes) chert breccias, class two included medium to fine grained soils (sandy clays, clayey sands), weathered BIF (lateritic soils) and class three included very fine grained soils (clays, shales and ferruginous clays).

The geologic materials overlying the aquifer and their corresponding thicknesses were used in conjunction with the soils vulnerability maps to classify geologic vulnerability into 3 classes; class one, highly fractured rocks, dolomite with karstic structures very coarse grained sandstone, conglomerates and gravelly formations; class two includes medium to fine grained sandstones, dolomites with less fractures/fissures, clayey sands and sandy clay formations. Class three, included clays, shales, dolerites, granites, fresh dolomite, cherts, quartzites.

For each aquifer two maps are produced, one based on soil vulnerability and the other on geological vulnerability (Fig. 2(a) and (b)). The soil and geological vulnerability maps are then overlain to produce a single vulnerability map with five possible vulnerability classes. Table 1 shows matrix of groundwater vulnerability class based on combination of soil and geological vulnerability.

The data were integrated in a GIS environment in order to spatially assess the soil, geological and groundwater vulnerability of the well field and the results are summarised in Fig. 2(a)–(c). Previous studies by Bekesi and McConchie (2002) show that GIS was used in integrating spatial vulnerability data with point borehole log information. The borehole log information at 82 boreholes was used to retrieve and spatially portray

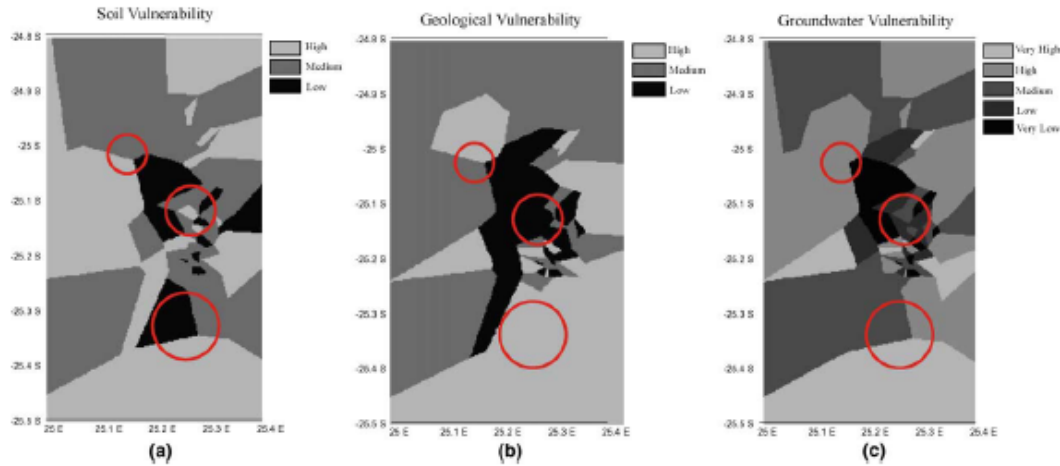


Fig. 2. (a)—Soil, (b)—geology and (c)—groundwater vulnerability maps.

Table 1  
Five aquifer vulnerability classes based on soil types and host geology

Soil vulnerability	Geologic vulnerability		
	G1–high	G2–medium	G3–low
S1–high	Very high	High	Moderate
S2–medium	High	Moderate	Low
S1–low	Moderate	Low	Very low

the various vulnerability classes in the well field by means of Thiessen polygons.

4. Results and conclusion

The results indicate that about 47% of the Kanye wellfield area is overlain by soils with high vulnerability to pollution (class 1 soils) Fig. 2(a); 44% of the area is overlain by soils of intermediate vulnerability (class 2 soils) and 9% of the area is overlain by soils of low vulnerability (class 3 soils). The geological vulnerability maps (Fig. 2(b)) show that 40% of the well field area is underlain by rocks with high permeability and significant fracturing thus of high vulnerability (class 1 rocks), 49% of the area is underlain by rocks of medium vulnerability (class 2 rocks) and 11% of the area is underlain by rocks of low vulnerability (class 3 rocks).

Considering the overall study area bounded between 25–25.4°E and 22.8–23.5°S, the ground water vulnerability map (Fig. 2(c)) indicates that 22% of the well field area is very highly vulnerable to pollution, 35% of the area is highly vulnerable to pollution, 34% is moderately vulnerable to pollution, 4.31% has a low vulnerability and 4.46% of the wellfield area has a very low vulnerability.

The results of this study indicate that the Kanye wellfield may be highly vulnerable to pollution if not prop-

erly managed. However, one should be cautious in the interpretation of these results due to the sparse and uncertain nature of the basic data used for this interpretation, and the inherent variability of the aquifer parameters.

The use of the polynomial estimator enabled consideration of simple uncertainty for the aquifer media characteristics modelling process, uncertainty being proportional to the size of the polygons. Estimates of the aquifer media characteristics in areas with only a few observations or few geological logs were considered to have higher uncertainty than areas with many observations.

In general, there is a high uncertainty of the groundwater pollution vulnerability classes in the Kanye aquifer system. The Northwest and Rammonedi wellfields have high uncertainty in the classes, while Kgwakgwe wellfield portrays a low level of uncertainty.

From the aquifer protection and management point of view, the question is how far one should establish a protection zone around the wellfield so as to protect the entire aquifer from pollution. This needs more study and field checking of the aquifer media characteristics maps. However, the study is an attempt to present a preliminary finding on the use of spatially distributed point data available to have an understanding of the regional variation of aquifer media characteristics and vulnerability to groundwater pollution.

The present study shows how vulnerable to pollution aquifers in Botswana can be and therefore it reinforces the recommendation by the Department of Water Affairs (1993) to establish groundwater protection zones over the most vulnerable areas which needs to be strictly adhered to in the development of groundwater resources.

**References**

- Beckman, H.E., Gieske, A., Seloilo, E.T., 1996. GRES: Groundwater recharge studies in Botswana, 1987–1996. *Botswana Journal of Earth Sciences* 1, 1–17.
- Bekesi, G., McConchie, J., 2002. The use of aquifer media characteristics to model vulnerability to contamination, Manawatu Region, New Zealand. *Hydrogeology Journal* 10, 322–331.
- DWA, Department of Water Affairs, 1993. Protection zones and guidelines for major wellfield, aquifers and dams in Botswana. Report prepared by Water Surveys, Botswana.