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NITRATE POLLUTION OF GROUNDWATER IN BOTSWANA

INTRODUCTION

During a review of water records and analytical methods at the Botswana Geological Survey in 1973 it became apparent that chemical analyses of some groundwater samples showed a cation-anion imbalance with an anion deficiency. When these samples were analysed for nitrate the balance was restored.

Nitrate analyses had not been made previously because information about an easy, reliable method was not available. However, after evaluating the various analytical methods, it was decided to use the colorimetric salicylate method (1) for nitrate determination on a regular basis.

Between 5-10% of all water samples analysed in the laboratory were subsequently found to have nitrate levels greatly in excess of WHO (2) recommendations as set out in Table 1.

The results were reported to government and concern was expressed at the highest level. Therefore the GS10 Groundwater Resources Evaluation Project team (3) was asked to investigate the causes of the pollution. Preliminary surveys (4,5,6,7) in 1976 had shown the extent of the pollution in major villages in eastern Botswana relying on groundwater supplies.

Table 1
WHO recommendations for nitrate levels in water (2)

	mg/l NO_3^-	category
general population	under 50	acceptable
	over 50 and under 100	borderline
	over 100	unacceptable
infants under 6 months	over 50	unacceptable

Table 2
Major villages with high levels of nitrate in their groundwater supplies

Village map reference	Name	Population actual (1971)	Dwellings	No of Boreholes with $NO_3^- > 20$ mg/l	Highest NO_3^- mg/l
1	Mochudi	6945	1578	9	603
2	Molepolole	9448	1763	18	422
3	Serowe	15364	2593	17	663
4	Kanye	10664	1884	2	251
5	Francistown	18613	3618	9	189
6	Palapye	5218	873	6	580
7	Mahalapye	11377	1876	4	227
8	Ramotswa	7991	1316	4	170

20 other villages (population less than 5000) were surveyed and nitrate values above 20 mg/l were detected in all of them.

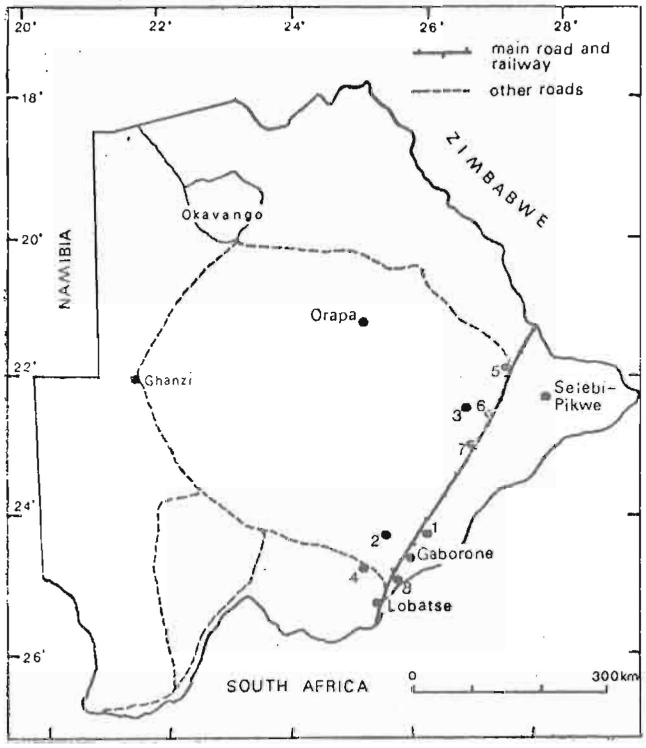

Figure 1

Location of major villages with high levels of nitrate in their groundwater supplies.

SIGNIFICANCE OF NITRATES IN THE GROUNDWATERS

Nitrate is an end-product of the decay of nitrogeneous material. This material could be fertilisers or animal and human excreta. Since the surveys showed that the nitrate contamination was generally confined to heavily used boreholes within village boundaries and that fertiliser is hardly used in Botswana, it was concluded that the nitrate was being derived from pit latrines. It is also common practice to defecate in secluded places.

There is a strong association between groundwater pollution and population density, but the major towns, Gaborone, Orapa, Selebi-Pikwe and Lobatse, which are served mainly by surface water, are unaffected.

CASE STUDY - MOCHUDI VILLAGE

A research study was funded through the GS10 project at Mochudi village (see Fig 1) during 1978 to confirm the source of the pollution.

Mochudi lies at the foot of a Waterberg sandstone escarpment resting on Basement Complex granites and gneisses. The specific study area was situated in a densely populated embayment in the escarpment underlain by Waterberg talus and weathered Basement Complex rocks. The soil cover is dark, clayey, fairly thin, grading downward within 2-3 m into weathered rock. Groundwater is extracted from quite shallow depths in the weathered rock and overburden.

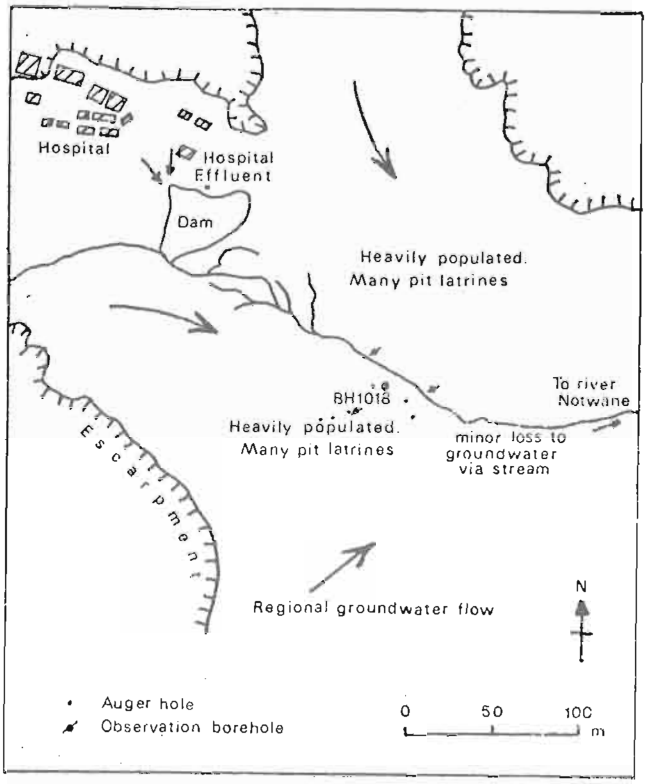

Figure 2

Mochudi Village and site plan of investigation area.

Rainfall in Mochudi averages 500 mm with 35% seasonal variability. It was assumed that recharge occurred during the study period since there was heavy rainfall.

Three observation boreholes were drilled around a public supply borehole and a 72 hour pump test carried out to determine the aquifer characteristics. Chemical and bacteriological analyses were made on soil and water samples from the unsaturated and saturated zones and a tracer study was used to determine the rate at which pollution travelled.

RESULTS

Pump test data indicated that the weathered granitic material forming the aquifer zone around Bh 1018 had a low transmissivity of 14-20 m^2/day. This implies that open fractures are few, the majority being filled by clayey weathering products. The drawdown after 21 hours pumping at the rate of 1 litre/sec was 9m (static water level 6 m).

Lithium chloride tracer injected into a pit latrine was detected in the supply borehole 25 m away after only 235 minutes. The steep hydraulic gradient between latrine and borehole was thought to have induced this rapid movement with flow occurring in open fissures.

Analyses of augered soil samples collected near the pit latrine showed high concentrations of nitrate (1-200 mg/100g) and chloride (1-40 mg/100 g) with highest values from the layer directly above the bedrock. Control samples from auger holes 40 m away showed only background concentrations (0,2 mg/100 g nitrate and 0,4 mg/100 g chloride). The zone of contaminated soil extend for at least 15 m either side of the pit latrine. This represents a massive quantity of potentially leachable nitrate and confirms the conclusion of the earlier studies that excreta disposal represents a major source of contamination to shallow groundwater supplies.

The bacteriological tests confirmed the presence of faecal coliforms in the supply borehole (10 coliforms/100 ml) and gross contamination (350 faecal coliforms/100 ml) in the observation borehole adjacent to the pit latrine.

RELATIONSHIP BETWEEN NITRATE CONTENT AND BACTERIAL POLLUTION

An attempt was made to determine the relationship between nitrate contents of groundwaters and bacterial population. However, no clear picture emerged; wells with little or no nitrate contamination were found with and without bacterial contamination. Similarly, wells with nitrate contamination were also found either with or without bacterial populations. It was concluded that the relationship between bacterial contamination and nitrate was not statistically significant (8). Similar findings were reported by Brookes and Cech (9) in their work on rural water supplies in Texas. However, these authors infer that there may be a complex non-linear relationship probably involving factors not presently well understood.

DANGERS OF NITRATE POLLUTION OF DRINKING WATER

The dangers of high nitrate concentrations in drinking water are well documented (10). Essentially, these are methaemoglobinaemia and carcinogenesis.

Methaemoglobinaemia

Nitrate can be reduced to nitrite by enterobacteria in the stomach. The nitrite is absorbed into the blood stream where it reacts with haemoglobin, the oxygen-carrying part of blood, to form methaemoglobin. Methaemoblobin cannot carry oxygen, so, if untreated, the condition leads to oxygen starvation of the tissues and possibly death for infants under the age of 3 months and cattle. Burden (11) reported cattle deaths from drinking water with high nitrate concentrations (70-870 mg/l nitrate) in Sudan. Studies by Shuval and Greuner (12) indicate that the oxygen deficient condition of methaemoglobinaemia can be transmitted from a mother across the placenta to her unborn child.

According to Berwick (13) methaemoglobinaemia can act synergistically with other diseases such as diarrhoea and anaemia which means, for example, that if a child has methaemoglobinaemia and then gets diarrhoea the health risks are much more serious.

Many factors are involved in human susceptibility to nitrates but in general young infants are the most vulnerable group for the following reasons:

1. infants have a lower stomach acidity than older children or adults. This allows the growth of certain microbes that contain enzymes capable of reducing nitrates to nitrites

2. foetal haemoglobin in the infant may be particularly more susceptible to conversion to methaemoglobin by the action of nitrites

3. the enzymes which can reduce methaemoglobin to haemoglobin are deficient in the young infant

4. the fluid intake of the young infant is higher than that of the adult in relation to body weight which means that more nitrate is consumed in relation to body weight.

Carcinogenesis

Nitrites, derived from nitrates, can react with amines and amides in the stomach to form nitrosamines. N-nitroso compounds can cause cancer in a wide range of animals and most are mutagenic. However, there is not enough data on either cancer-inducing dosages of nitrate/nitrite nor on the complex inter-relationships of environmental and biological mechanisms of carcinogenesis to draw definite conclusions.

IMPLICATIONS OF NITRATE IN WATER SUPPLIES

These studies clearly establishes the serious groundwater pollution hazard represented by pit latrines in hydrogeological environments such as those widely encountered in eastern Botswana. There may be a major build-up of nitrogeneous effluent in the soil and weathered bedrock surrounding pit latrines from which high quantities of nitrate are leached.

If pit latrines are close to water supply boreholes and pumping results in rapid flow from latrine to borehole, potentially grave risks to public health arise. Bottle fed infants are at particularly high risk if nitrate contaminated waters are used in preparing feeds. Boiling water will concentrate, not remove, nitrate.

The government of Botswana is well aware of the dangers of groundwater pollution and have ordered that the polluted wells be closed and alternative groundwater supplies provided for many of the listed villages (Table 2).

THE SIGNIFICANCE OF NITRATE TO WATER ENGINEERS

The importance of nitrate values for the water supply engineer is as an indicator that pollution has taken place. With this knowledge steps can be taken to locate the possible sources of pollution, stop it at source, or, failing this, protect the water supplies from further pollution. At the moment there are no economic methods of removing nitrate from polluted water supplies.

The engineer should remember that nitrate values of any particular water source can fluctuate seasonally depending on the period of recharge. Once a source has been found to have a nitrate value greater than 20 mg/l it should be tested regularly to determine whether there may be higher nitrate values at different times of the year.

Simple field methods of nitrate analysis are available and these can greatly assist field engineers in routine monitoring of water quality (Appendix 1).

APPENDIX 1

Field methods of testing for Nitrates and Nitrites

Dip stick tests for Nitrate and Nitrite have been developed recently by Merck. These give a semi quantitative determination of Nitrate in steps of 10, 30, 100, 250 and 500 mg/l of Nitrate and 1, 5, 10, 25, 50 mg/l of nitrite. The test strip is dipped into the water, removed and if nitrate is present a red-violet colour is produced on the sensitised part of the strip within 2 minutes. After this time the colour developed is compared to a colour scale printed on the side of the container and the amount of nitrate present read off.

The test strips enable simple and rapid semi-quantitative determination on site and can be used by relatively untrained staff. An on-site assessment of the likely sources of pollution can be made immediately and demonstrated visually to local officials and health workers. The use of test strips allows the field worker to screen water samples and indicates whether special samples need to be taken for more accurate laboratory analysis. The approximate cost is £5 for 100 strips, contained in an aluminium can 10 cm long and 3 cm diameter. At 5p per determination the cost is negligible compared to the field worker's transportation costs. The strips have a field life of about 1 year.

Other field test kits available for nitrate determinations are produced by Lovibond (UK) and Hach (USA). The kits use disc colour comparators and addition of chemicals to the sample contained in glass tubes to produce colours. The Hach kit uses encapsulated reagents which are opened using nail clippers. The reagents are stable in hot climates for about 6 months. The cost is about £28 for the kit and £8 for reagents sufficient for 100 tests. The kits are packed in carrying cases 20 x 15 x 15 cm.

The values obtained are obviously not as accurate as those which could be measured using sophisticated laboratory methods but the field engineer may not require accuracy and is unlikely to have the support of sophisticated laboratories and staff.

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