Relationship between nitrogenous pollution of borehole waters and distances separating them from pit latrines and fertilized fields

Basie Vinger [1], *Mbhuti Hlophe[2] and Mailoo Selvaratnam[2].

[1]Department of Chemistry, University of Limpopo (Turfloop Campus), Sovenga 0711, Republic of South Africa.
[2]Department of Chemistry, North-West University (Mafikeng Campus), Mmabatho, 2735, Republic of South Africa.
mbhuti.hlophe@nwu.ac,za

Abstract: The occurrence of the following nitrogenous pollutants, namely ammonium, nitrite and nitrate ions, was investigated in groundwater (borehole) sources of two villages in North West Province of South Africa. The study was carried out for two reasons. The Department of Water Affairs and Forestry (DWAF) in Mmabatho had expressed anxiety over anomalous levels of nitrate ion (which can be reduced to the toxic nitrite ion) in some groundwater sources in the province (and this included some groundwater sources in the two villages). The concentrations of the nitrogenous pollutants were monitored by differential pulse polarography (DPP). This electrochemical method was selected because it is fast, has low detection limits and is virtually free of interferences. The study indicated that the main pollutant in the groundwater sources was nitrate ions whose concentrations were higher than 25 ppm in some borehole waters. This is more than two times higher than the 10 ppm N specification recommended by the South African National Standard (SANS) for drinking water. The study also indicated that the concentrations of ammonium and nitrite ions in the borehole waters studied are not a health risk to the communities. Important sources of groundwater pollution are pit latrines and maize fields treated with nitrogen fertilizers. It was found that groundwaters (borehole water) were polluted with nitrate ions when the distances of the pit latrines and fertilized maize fields were respectively less than 18 m and 13 m from the boreholes. The pollution was more pronounced when the water table was shallow.
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1. Introduction

The majority of people in South Africa drink untreated groundwaters and they are mainly from boreholes (Modise and Krieg, 2004). It is important, therefore, to check whether borehole waters are polluted. An important type of pollution is due to NO_3^-, NO_2^- and NH_4^+ ions, which are inorganic ions containing nitrogen. Studies have shown that the concentrations of nitrate ions (NO_3^-) is high in many groundwaters in South Africa (Modise and Krieg, 2004; Fourie and van Ryneveld, 1995; Sililo and Saayman 2001; Tredoux et al, 2000; Bhagwan et al, 2006; Conrad et al, 1999; Tredoux, 2004; Fourie and van Ryneveld, 1994; Xu and Braune, 1995; Terblanche, 1991; Jackson, 1998). and that it is particularly high in a belt running in a north-easterly direction from the Northern Cape through the North West Province to Limpopo Province (Tredoux, 2000).

Nitrate ion is a health risk because it is reduced to the toxic nitrite ion (NO_2^-) by microbiological processes in our stomachs. Nitrite ions reduce the oxygen-carrying capacity of blood and may cause methaemoglobinemia in infants (Girard and Hillaire-Marcel, 1997; Jacks et al, 1999; Ramaraju et al, 1999; Wakida and Lerner, 2005; Chiroma et al, 2007; Banks et al, 2007; Ohou et al, 2008; Suthar et al, 2009; Hesseling et al, 1991; Lewis et al, 1980) and they can also react with amino compounds, in many media, to form nitrosoamines which are strongly carcinogenic (Girard and Hillaire-Marcel, Ramaraju et al, 1997; Wakida and Lerner, 2005; Suthar et al, 2009).

Nitrogenous pollutants reach groundwater sources by several pathways, the most important of which are seepage of water containing these pollutants from the following sources (Water Quality Management Policies and Strategies in RSA. April, 1991) : decayed vegetation and animal matter; pit latrines; sewage; domestic and farm effluents; fertilizers applied to farm lands. The main purpose of this study was to investigate pollution due to pit latrines and nitrogenous fertilizers The main purpose of this study was to investigate pollution due to pit latrines and nitrogenous fertilizers and the objectives were to: determine the concentrations of NO_3^-, NO_2^- and NH_4^+ ions in some selected borehole waters; find out whether there is a correlation between these concentrations and the distances separating the boreholes and pollution sources (pit latrines and fertilized maize fields); make suggestions for preventing pollution of borehole waters.

A pit latrine is easy to construct and maintain. A hole having a depth of about 2 metres is generally dug in the ground over which a seat is placed and this is enclosed in some structure that has a roof and a door (Palmer, 1981) . Liquid waste will infiltrate into the surrounding soil and the amount that can be absorbed by the soil will depend mainly on its composition and texture. Nitrogenous pollution due to pit latrines has been studied by many workers (Bhagwan et al, 2006; Conrad et al, 1996; Tredoux, 2004; Fourie and Ryneveld, 1994; Xu et al, 1995; Terblanche, 1991; Jackson, 1998; Girard and Hillaire-Marcel, 1997; Jacks, 1999; Banks et al, 2007; Ohou et al, 2008; Palmer, 1981; Reed, 1994). Their studies show that nitrogenous pollution depends on many factors, some of the more important of which are: number and sizes of pit latrines; distance of pit latrine from boreholes; depth of aquifers; soil and rock composition and their textures around the aquifers.

Two villages (Schoongezicht and Welverdiend) situated in the Ditsobotla District of North West Province were selected for the study. This area was chosen because of information supplied by the Department of Affairs (Mmabatho) that waters in these areas are polluted with nitrate ions. Topography of area is illustrated in Figure 1.

The land slopes very gently to the north-east at a gradient of 1 in 50 metres (Brinn, 1991). Welverdiend is at a lower altitude than Schoongezicht and water flows from Schoongezicht to Welverdiend. The water levels at Schoongezicht and Welverdiend were respectively about 9 metres and 6 metres below ground level. Water samples from nine boreholes were studied. Details of the boreholes relevant to this study are shown in Table 1.

Row 7 in this Table shows the distances separating the pit latrines and maize fields from the boreholes. Rows 2, 3, 4, 5 and 6 give, respectively, information about borehole location, borehole number, equipment with borehole, borehole depths and water level depths. Row 8 gives the number of pit latrines close to each borehole.

2. Materials and Methods

(a) Apparatus

BAS–100B/W Electrochemical Workstation was used to obtain polarograms for the standard solutions and the water samples. Oyster pH meter was used for measuring the pH and temperatures of the water samples collected.

b) Collection and storage of groundwater samples

Water samples from the nine boreholes were collected once a week for six weeks during the winter season, June/July. Sampling was done in the morning and the water samples were collected in 1 litre polyethylene bottles. The pH and temperature of each water sample was then recorded and 1 millilitre of 10 ppm $HgCl_2$ solution (preservative) was added to each sample. Until analysis, the samples were kept in a refrigerator.

(c) Preparation of standard solutions of NO_3^-, NO_2^- and NH_4^+ ions for obtaining calibration curves

Analar potassium nitrate (KNO_3), sodium nitrite ($NaNO_2$) and ammonium sulphate, $(NH_4)_2SO_4$, were used respectively to prepare 1 000 ppm N stock solutions of NO_3^-, NO_2^- and NH_4^+ ions. These solutions were then appropriately diluted to prepare the solutions for obtaining calibration curves (concentration range: 2 ppm – 20 ppm).

(d) Preparation of o-nitrophenol from NO_3^- ions (Metrohm Application Bulletin No. 70e,1979; Vinger, 1998)

2.0 cm^3 of the NO_3^- solution was mixed with 2.0 cm^3 of phenol in a beaker. 8.0 cm^3 of concentrated sulphuric acid was then added slowly while swirling the contents of the beaker, to prepare o-nitrophenol.

(e) Preparation of diphenyl nitrosoamine from NO_2^- ions (Barsotti et al, 1982; Vinger, 1998)

3.0 cm^3 of diphenylamine was added to a solution containing 2.0 cm^3 of the NO_2^- solution and 10.0 cm^3 of potassium thiocynate (KCNS). Diphenyl nitrosoamine is then formed.

(f) Preparation of methyleneimine from NH_4^+ ions (McLean, 1978; Vinger, 1998)

To 5.0 cm^3 of the buffer solution of pH 4, 5.0 cm^3 of formaldehyde and 15.0 cm^3 of the NH_4^+ ion solution were added. The mixture was then heated on a water bath for 5 minutes, to form methyleimine.

(g) Procedure for obtaining a Differential Pulse Polarogram (DPP)

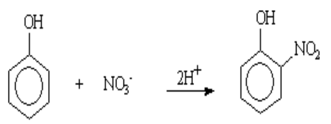
10 cm^3 of the solution (of o-nitrophenol, dipheny nitrosoamine or methyleimine) was transferred into a polarographic cell. The solution was purged for 5 minutes with high purity nitrogen gas (to remove dissolved oxygen) and its DPP was recorded using appropriate instrument parameters. A typical DPP, for an o-nitrophenol solution (prepared from NO_3^-), is shown in Figure 2.

(h) Determination of concentrations of NO_3^-, NO_2^- and NH_4^+ ions

Differential pulse polarography (Skoog et al, 1992), (DPP), the most sensitive polarographic method, was used for the determination of the concentrations of NH_4^+, NO_3^- and NO_2^- ions in the water samples collected from the boreholes. For recording the differential pulse polarograms, a BAS–100B/W electrochemical workstation was used. The working electrode (WE) was a dropping mercury electrode (DME) and the counter (AE) and reference electrodes (RE) were respectively a coiled platinum wire and silver /silver chloride.

Determination of nitrate ions

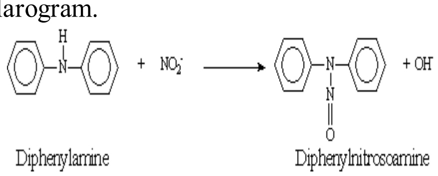
The concentration of nitrate ion (NO_3^-) was determined by reacting it with phenol in an acidic medium to form ortho-nitrophenol (Metrohm Application Bulletin No. 70e, 1979) and then obtaining a differential pulse polarogram of the solution obtained.



(1)

Determination of nitrite ions

The concentration of nitrite ion (NO_2^-) was determined by reacting it with diphenylamine at a pH of about 1.5 to form diphenylnitrosoamine (Barsotti et al, 1982) and then obtaining its differential pulse polarogram.



(2)

Determination of ammonium ions

The concentration of ammonium ions (NH_4^+) was determined by first converting it into methyleneimine ($CH_2=NH$) by reacting with excess formaldehyde (HCHO) in an acidic medium (McLean et al, 1978)

$$\underset{\text{Formaldehyde}}{H_2C=O} + NH_4^+ \longrightarrow \underset{\text{Methyleneimine}}{CH_2=NH} + H_3O^+ \quad (3)$$

and then obtaining a differential pulse polarogram of the methyleneimine solution obtained.

The concentration of each nitrogen species in a water sample was determined from the peak current (i_p) by making use of a calibration curve of peak current versus concentration.

Determination of concentrations from polarograms

The concentrations of NO_3^-, NO_2^- and NH_4^+ ions in the various water samples were determined from the peak currents (i_p, see Figure 2) in the appropriate polarograms, by making use of calibration curves that were obtained from plots of peak current (i_p) versus concentration of the ion.

The concentrations of NO_3^-, NO_2^- and NH_4^+ ions, obtained from the peak currents of the various borehole water samples over the six weeks sampling period are given in Table 2.

3. Results and discussion

The results in Table 2 do not show any trends in the concentrations of the ions from week to week. The average value (for the six weeks) of the concentration of each ion in each borehole was therefore taken to be its best value and this is shown in Table 3.

The ammonium and nitrite ion concentrations (columns 2 and 3 in Table 3) in all the water samples tested are below the South African National Standard (SANS – 241) (South African National Standard, SANS 241, 2005) specification for drinking water, which is less than 2 ppm for NH_4^+ and 10 ppm for NO_2^- ion. These ions should not therefore cause any health problems in the borehole waters tested.

Now consider NO_3^- ions. Their concentrations in four of the borehole water samples tested are greater than the SANS specification for drinking water ,which is less than 10 ppm NO_3^-. In two of these borehole water samples (77265 and Masibi) nitrate concentrations are greater than 20 ppm which are high-risk concentrations (A Guide for the Health Related Assessment of the Quality of Water Supplies, 1996). In two of the borehole water samples (77272 and 77266) the nitrate concentrations are between 10 and 20 ppm and these are in the low-risk range (Reed, 1994).

Table 4 shows the relationship between the nitrate ion concentration (*c*) and the distance (*d*) separating the boreholes and the pollution sources (pit latrines, P.L., and maize fields, M.F.).

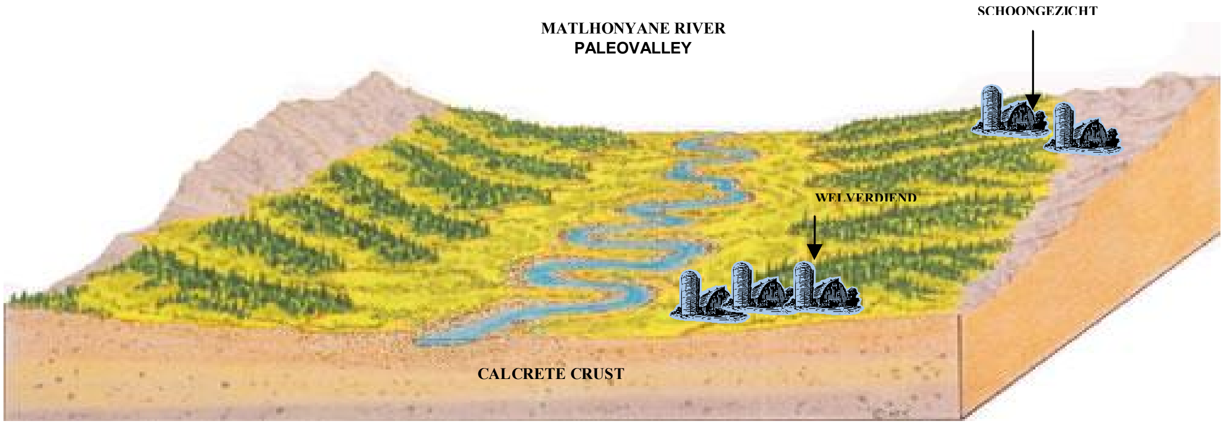


Figure 1: A diagram showing the topography of the Bethel-Itsoseng area and the positions of the two villages (Schoongezicht and Welverdiend).

TABLE 1: Selected villages and boreholes sampled

	Schoongezicht					Welverdiend			
Place	Bontle	Field	Clinic	Field	Masibi	Field	Field	Motswai	Cafe
B/No	77085	77272	77271	77893	Private	77266	77265	77355	Private
Equipment	Hand pump	Windmill	Hand pump	Windmill	Hand pump	Windmill	Hand pump	Hand pump	Hand pump
Depth (m)	37	76	71	Not known	Not known	Not known	Not known	Not known	Not known
Water level (m)	3	9	9	Not known	Not known	7	6	Not known	Not known
Location	13 m from 2 pit latrines	12 m from maize field	In the field	30 m from maize field	11 m from 4 pit latrines	50 m from 2 pit latrines	10 m from maize field	84m from 5 pit latrines	26 m from 1 and 24 m from 2 pit latrines
No. of pit latrines	2	0	4	0	4	2	0	5	3

B/No = Borehole number
Bontle = Bontle Primary School
Motswai = Motswaiso Middle School
Masibi = Mr Masibi's place
Café = Regoikantse café

TABLE 2: Concentrations in ppm of NH_4^+, NO_2^- and NO_3^- ions in borehole water samples.

	Week 1			Week 2			Week 3			Week 4			Week 5			Week 6		
B.N.	$^{C}NH_4^+$	$^{C}NO_2^-$	$^{C}NO_3^-$	$^{C}NH_4^+$	$^{C}NO_2^-$	$^{C}NO_3^-$	$^{C}NH_4^+$	$^{C}NO_2^-$	$^{C}NO_3^-$	$^{C}NH_4^+$	$^{C}NO_2^-$	$^{C}NO_3^-$	$^{C}NH_4^+$	$^{C}NO_2^-$	$^{C}NO_3^-$	$^{C}NH_4^+$	$^{C}NO_2^-$	$^{C}NO_3^-$
77893	ND	1.00	3.19	ND	0.62	3.20	0.003	ND	2.44	1.34	ND	6.58	1.89	ND	3.88	0.23	ND	1.41
77265	ND	ND	31.9	1.80	ND	33.6	1.01	ND	18.6	0.39	ND	43.2	2.89	ND	20.8	0.03	ND	25.4
77266	ND	ND	10.0	ND	ND	11.1	ND	ND	6.89	2.10	0.11	9.89	5.37	ND	13.1	ND	ND	11.8
77085	ND	ND	11.2	2.00	ND	11.3	ND	ND	7.13	0.82	0.09	9.53	2.91	ND	9.59	0.16	ND	10.3
77271	1.44	N.D	9.09	3.10	ND	10.2	0.02	ND	6.74	ND	ND	11.1	ND	ND	9.59	0.20	ND	8.19
77355	ND	3.89	2.25	1.50	ND	3.50	ND	ND	3.71	ND	0.10	4.84	ND	ND	6.31	0.44	ND	4.01
77272	-	-	-	0.50	ND	10.4	0.63	ND	8.54	1.56	ND	14.2	2.82	ND	10.8	0.85	ND	12.2
Café	ND	ND	6.49	1.60	ND	7.20	0.50	ND	5.92	1.04	0.35	5.87	ND	ND	10.7	ND	ND	7.30
Masibi	ND	0.94	14.3	8.30	ND	21.6	ND	ND	21.8	ND	ND	34.9	ND	ND	30.2	ND	0.09	36.2

ND = not detected

B.N. = borehole number

TABLE 3: Average concentrations in ppm of NH_4^+, NO_2^- and NO_3^- in borehole water samples for all 6 weeks.

Borehole number	$^{C}NH_4^+$	$^{C}NO_2^-$	* $^{C}NO_3^-$
77893	0.6	0.3	3.5
77265	1.0	0	28.9
77266	1.2	0.02	10.5
77085	1.0	0.02	9.8
77271	0.8	0	9.2
77355	0.3	0.7	4.1
77272	1.3	0	11.2
Café	0.5	0.06	7.2
Masibi	1.4	0.17	26.5

* The precision of the concentration of the nitrate ion results has been expressed in terms of the standard deviation.

Table 4: Relationship between concentration of nitrate ions and distance from pollution source.

Borehole	77265	Masibi	77272	77266	77085	77271	Cafe	77355	77893
c/ppm	29.0	26.5	11.2	10.5	9.8	9.2	7.3	4.1	3.5
d/m	10	11	12	50	13	-	26	84	30
Pollution source	M.F.	P.L. (4)	M.F.	P.L. (2)	P.L. (2)	P.L. (4)	P.L. (3)	P.L. (4)	M.F.

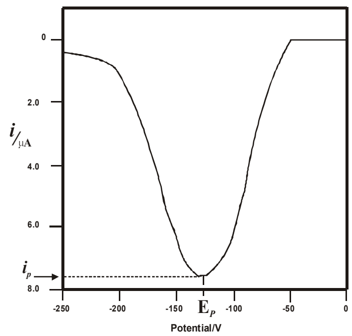


Figure 2: A typical differential pulse polarogram (DPP) to determine nitrate ions

The data in Table 4, except for borehole 77266, suggest a correlation between nitrate ion concentration and the distance separating the boreholes from the pollution source. They show that water samples in boreholes that have the highest concentrations of nitrate ions (77265 and Masibi) are at the closest distances to a pollution source, and those that have the lowest concentrations (boreholes 77385 and 77893) are far away from pollution sources.

From this study it appears that effluents from pit latrines and fertilizers applied to maize fields cause nitrate pollution of borehole waters. The nitrate pollution occurs if the pollution source is less than about 12 metres from boreholes.

This results obtained from this study is essentially in agreement with earlier reports by Xu and Braune, (1995); Ohou et al, (2008); Conrad et al, (1999); and Tredoux, (2004).

5. Conclusions and recommendations

This study suggests that pollution of borehole waters is likely if the distance separating the boreholes from a pollution source (pit latrines, fertilized maize fields) is less than about 12 metres.

The following could be done to prevent or reduce pollution of borehole waters:

(a)Proper construction, operation and maintenance of sanitation systems. There is a need for appropriate legislation, and its enforcement, concerning the specifications, siting, design, construction and maintenance of pit latrines and septic tanks.

(b)Planting of trees and reeds around boreholes. Nitrogenous pollutants will then be absorbed by the roots of these trees and reeds.

(c)Controlled application of fertilizers to maize fields.

(d)Education of the people in rural communities as to how pollution of borehole waters can be prevented.

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***Corresponding author:**
Dr M. Hlophe
Department of Chemistry
North-West University, Mafikeng Campus
Private Bag X2046, Mmabatho, South Africa.
E-mail: mbhuti.hlophe@nwu.ac.za.

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