Groundwater contamination due to pit latrines located in a sandy aquifer

A CASE STUDY FROM MAPUTALAND

David Still &
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WATER RESEARCH COMMISSION

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EXECUTIVE SUMMARY

There is a widespread perception that pit latrines should not be used in areas where the groundwater is used for domestic water consumption. South Africa's groundwater protocol does not forbid pit latrines in such areas, but advises caution and moreover recommends that pit latrines are located at least 75 metres from water sources.

This report describes local and international research in this field, and examines the justification of the 75 metre rule. What exactly are the hazards posed by pit latrines, and what are the real risk situations?

The report describes field research which has been conducted in the Maputaland area of KwaZulu-Natal, where there are large numbers of both pit latrines and shallow wells. The report describes the observations of water quality in a range of well types spread throughout the area, and also describes the water quality in the groundwater sampled close to pit latrines. The latter were monitored for faecal coliform bacteria and nitrates.

The report concludes that a fine sandy soil is an effective filter medium and that pit latrines pose a negligible health risk in such an area, with the safe distance for water abstraction being more like 20 metres. The report shows that water quality in wells depends on well design and how the well is used. The report shows that properly designed and maintained wells produce water of good quality.

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1. INTRODUCTION

There is a widespread perception that pit latrines should not be used in areas where the groundwater is used for domestic water consumption. South Africa's groundwater protocol (Department of Water Affairs and Forestry, 1997) does not forbid pit latrines in such areas, but advises caution and moreover recommends that pit latrines are located at least 75 metres from water sources.

One such area is the coastal plain of northern KwaZulu-Natal, home to several hundred thousand people. These people have traditionally collected water from shallow unprotected wells, which are dug in or near to river beds and pans. There is no waterborne sanitation in the area. All defecation is either carried out in the bush, or using pit latrines. The water table depth varies according to the topography, but is generally between 5 and 20 metres below the surface.

A blind application of the groundwater protocol would indicate that, due to all the pit latrines of the area, **the water under the surface must be contaminated, and that the groundwater is therefore unsafe to drink. Is this in fact the case?**

2. HEALTH RISKS ASSOCIATED WITH FAECAL WASTE IN SOIL

There are a number of pathogens which are found in faecal waste, including viruses, bacteria, protozoa and helminths (parasitic worms). The latter two types are effectively filtered out by soil, while the former can be carried some distance with seepage water. The travel distance varies according to a number of factors, the most important of which are: the seepage flow; the size of soil particles; the soil pH; and the temperature. Table 1 shows the results from 21 different case studies published over the period 1932 to 1979. The evidence from Table 1 is that bacteria are generally removed within 20 to 30 metres of the disposal site. While there are cases where faecal coliforms have been detected much further away (up to 500 metres), an examination of the data shows that these cases are associated with high hydraulic loading (infiltration basins, percolation beds etc) and highly permeable soils (typically gravels). Guidelines and regulations typically require pit latrines to be 30 metres or more from water sources (boreholes, streams etc), as shown in Table 2.

Table 1: A summary of studies of bacterial transport through soils (Crane and Moore, 1983)

Nature of pollution	Organisms	Medium	Measured distance travels	Time of travel	Reference
Sewage trenches intersecting groundwater	*Bacillus coli*	Fine sand	19.8 m	27 wks	Stiles and Crohurst (1923)
Sewage trenches intersecting groundwater	Coliforms	-	70.7 m	-	Warrick and Muegge (1930)
Sewage in pit latrine intersecting groundwater	*Bacillus coli*	Fine and coarse sand	24.4 m	-	Caldwell (1937)
Sewage in pit latrine intersecting groundwater	Bacillus coli	Sand and sandy clay	10.7 m	8 wks	Caldwell and Parr (1937)
Sewage in pit latrine intersecting groundwater	*Bacillus coli*	Fine and medium sand	3.1 m	-	Caldwell (1938)
Primary and treated sewage in infiltration basins	Coliforms	Fine sandy loam	0.6-4 m	-	Butler et al. (1954)
Diluted primary sewage injected subsurface	Coliforms	Aquifer	30 m	33 hrs	McGauhey and Krone (1954)
Canal water in infiltration basins	*Escherichia coli*	Sand dunes	3.1 m	-	Baars (1957)
Subsurface injections	Enterococci	-	15 m	-	Fournelle (1957)
Secondary sewage in infiltration basins	Coliforms	Sandy gravels	0.9 m	-	McMichael and McKee (1966)
Tertiary treated wastewater in percolation beds	Faecal coliforms and faecal streptococci	Coarse gravels	457.2 m	15 da	Merrell (1967)
Primary sewage injected subsurface	Coliforms	Sand and pea gravel aquifer	30.5 m	35 hrs	Krone et al. (1958)
Secondary sewage injected subsurface	Faecal coliforms	Fine to coarse sand aquifer	30.5 m	-	Wesner and Baier (1970)
Tertiary treated wastewater in percolation beds	Coliforms	Sand and gravel	20 m	-	Ana'ev and Demin (1971)
Inoculated water and diluted sewage injected subsurface	*Bacillus stearothermophilis*	Crystalline bedrock	13.5 m	24-30 hr	Allen and Morrison (1973)
Tertiary treated wastewater in infiltration basins	Coliforms	Fine to medium sand	6.1 m	-	Young (1974)
Secondary sewage in infiltration basins	Faecal coliforms	Fine loamy sand to gravel	9.1 m	-	Bower et al. (1974)
Primary sewage in infiltration basins	Faecal streptococci	Silty sand and gravel	183 m	-	Schaub and Sorber (1977)
Secondary sewage effluent in infiltration bsins	Faecal coliforms and faecal streptococci	Fine loamy sand to gravel	9 m	-	Gilbert et al. (1976)
Septic tank tile effluent	Total coliforms Faecal coliforms	Fine loamy soil	6.1 m 13.5 m	-	Reneau and Pettry (1975)
Inoculated effluent in tile line	*E. coli*	Silty clay loam	20 m	5 hr	McCoy and Hagedorn (1979)

Table 2: Recommended safe distances between domestic wells and various on-site sanitation systems (Van Ryneveld and Fourie, 1997, citing Romero, 1972)

SOURCE OF POLLUTION	RECOMMENDED DISTANCE (m)			
	California	**Colorado**	**FHA***	**USPHS****
Septic tank	16	30 m from point of juncture between well casings and aquifer	16	16
Sewer lines with water tight joints	3	As above	3	3
Percolation field	30	-	30	30
Absorption bed	30	8 m minimum horizontal distance	30	-
Seepage pit	30	As above	30	30

** Federal housing Authority*
*** United States Public Health Service*

More recently, Abbaszadegan (2003) tested 448 wells used for drinking water in the USA, and found evidence of infective viruses in 4.8% of them and bacteria (coliforms) in 15.1%. Although he found viruses as far as 1 000 metres from one source of contamination, he also found viruses in two instances where there was no known source of contamination. In his data the incidence of bacteria and viruses in the wells with no known source of contamination and those in proximity to a known source of contamination are not very different. Unfortunately the number of wells tested with no known source of contamination (33) is much smaller than the number of wells tested with a suspected source of contamination (415). One fact that is evident from Abbaszadegan's work, is that any groundwater source may be exposed to contamination (whether the source of the contamination is apparent or not), and therefore every source must be tested on a regular basis. As a precaution all water should be disinfected before drinking.

A second concern is the effect of faecal wastes on levels of nitrates in the soil. High nitrates in the water supply can pose a minor health risk to breastfeeding infants. The preferred level of Nitrogen in groundwater is less than 10 mg/litre, but sustained levels of over 20 mg/litre are required before any significant health risk is posed (Water Research Commission, *Quality of Domestic Water Supplies*, 1998 refers). In reality nitrate concentrations are reduced by dilution and by natural denitrification processes in the soil, so that concentrations in excess of 20 mg/l would require heavy and continuous applications of waste.

Another area of interest is the lifespan of pathogens in soil. Studies quoted by van Ryneveld and Fourie (1997) indicate that most die-off occurs within 10 days, although certain organisms under certain conditions will last for up to 100 days, and times of as long as a year are recorded in special cases (see Tables 3, 4 and 5).

Table 3: Factors affecting survival of enteric bacteria in soil
Gerba et al. (1975) cited in Ryneveld and Fourie (1997 pg 287)

Factors	**Remarks**
Moisture content	Greater survival time in moist soils and during times of high rainfall
Moisture-holding capacity	Survival time is less in sandy soils than in soils with greater water retention capacities
Temperature	Longer survival times at low temperatures; longer survival in winter than in summer
pH	Shorter survival time in acid soils (pH 3-5) than in alkaline soils
Sunlight	Shorter survival time at soil surface
Organic Matter	Increased survival time and possible regrowth when sufficient amounts of organic matter are present

Table 4: Survival times of excreted pathogenic bacteria and viruses in soil at 20 to 30ºC*Feachem et al. (1983) cited in Ryneveld and Fourie (1997 pg 288)*

Pathogen	Survival time (days)
Viruses: Enteroviruses	<100 but usually <20
Bacteria	
Faecal coliforms	<70 but usually <20
Salmonella spp.	<70 but usually <20
Vibrio cholerae	<20 but usually <10

Table 5: Survival times of pathogenic bacteria
** cited by Patterson et al. (1971); in turn cited by Viraraghavan, (1978); although original references not given by Viraraghavan.*

Pathogen	Medium	Survival time	Reference
Salmonella tryphosa	Soil	25-41d	Beard (1938)*
Coliform bacteria	Soil	90d	Malin and Snelgrove (1958)*
Salmonella tryphosa		165d	Warrick and Muegge (1930)*
E. coli	Soil	730d	Mom and Schaafsma (1933)*
E. coli	other medium	970d	Warrick and Muegge (1930)*
Salmonella	Sand	44d	Yitzaghi (1971)**
E. coli	Water (recharge well)	63d	Goldshmid et al. (1972)**
E. coli	Groundwater	90-105d	Krudryavtseva (1972)**
E. coli	Groundwater	120-135d	Krudryavtseva (1972)**

In any discussion on contamination of water, it should be stressed that faecal coliforms are *indicator* organisms, and are not themselves pathogens. They occur naturally in very large numbers in the digestive tracts (and on the bodies) of healthy individuals and do not of themselves cause illness. However their presence in water merely does indicate that the water may be exposed to pathogens which are associated with faecal waste.

3. THE DWAF GROUNDWATER PROTOCOL

The Department of Water Affairs and Forestry (DWAF) have developed a protocol for the management of groundwater contamination from on-site sanitation. In the DWAF document it states that "The aim of the protocol is to ensure that reasonable measures are taken to guard against contamination of valuable groundwater resources by inappropriately located or designed sanitation systems."

The protocol consists of a number of steps (DWAF 1997, p8):

1. Assessment of groundwater potential
2. Evaluation of groundwater use
3. Assessment of sensitive "flag" situations
4. Evaluation of pollution risk to the groundwater resource
5. Evaluation of measures to reduce the risk
6. Implementation of risk reduction measures

The protocol is accompanied by a set of guiding principles (DWAF 1997 pg 7):

- A hydrocensus should be undertaken of all water sources within a 2km radius of the area being developed. (The size of the area may be reduced or decreased, as long as a representative number of boreholes are assessed).
- The community should be involved in the hydrocensus and made aware of the health impacts related to contamination of groundwater resources used for water supply purposes.
- No on-site sanitation systems should be installed within 50 m of a water supply source (spring or borehole) and vice versa.
- No high loading (schools, clinics etc) sanitation system should be installed within *75 m* of a groundwater supply source and vice versa.
- All boreholes should be completed with a sanitary seal and appropriate wellhead construction aimed at preventing surface water from entering the borehole.
- No activity should be allowed within 30 m of a borehole other than those associated with collecting water.
- If appropriate and practical, new boreholes should be sited outside of villages and up-gradient of potential sources of contamination. Borehole site selection must take into account geohydrological criteria and potential sources of contamination which could impact on the suitability of the water for consumption.
- All failed or abandoned boreholes should be backfilled and sealed after the project manager and/or the client has had an opportunity to measure that the borehole was drilled to specification.
- All groundwater supply systems must have regular monitoring of the water quality.

These are guidelines, not rules, and should be applied and adapted specific to each site.

4. DESCRIPTION OF THE MBAZWANA CASE STUDY

For the last six years Partners in Development have been engaged in both well construction and VIP latrine construction programmes in the region around the town of Mbazwana in Maputaland. Since 1998 water quality samples have regularly been taken from a variety of different types of well (protected/unprotected, private/public, tube/ring). These samples have been analysed for faecal coliforms as well as for nitrates.

In addition to the sampling from wells, a monitoring site was set up around a pit latrine which has been in existence since 1995. Monitoring wells were installed in the direction of groundwater flow at increasing intervals from the pit latrine (1, 10, 20, 30 and 50 metres), as well as one background well set 90 metres away perpendicular to the groundwater flow direction.

Figure 1 shows the pit latrine where the monitoring took place.

Figure 1: The pit latrine (in use for more than five years), around which monitoring for groundwater contamination took place over a fourteen-month period. The first monitoring hole, just one metre from the pit, can be seen on the left.

The sampling methods used were as follows:

Pit Latrine Site Monitoring Procedure

i) All monitoring holes at the latrine sites were bailed one day before testing. Bailing was carried out with a small galvanised iron bucket. It was not sterilised in any way. Monitoring holes were bailed until all water had been bailed out (taken as when the bucket came up only 1/4 to ½ full).

ii) Agar plates were prepared one day before monitoring and were stored in the fridge.

iii) Before the taking of the sample the bailer and rope were wiped down with a small amount of ethanol. The inside of the bailer was not rinsed with anything. The sampler wore rubber gloves during monitoring (when they were available). Care was taken not to touch the bucket once it had been wiped with the ethanol. Care was also taken to make sure the bucket touched nothing else before it was lowered down the monitoring hole.

iv) The bucket was then lowered down the hole and one bucket full of water was removed. This was carefully poured into the sterile sampling bottles which were then placed into a cool box.

v) Between each monitoring hole, the bucket was once again wiped down with ethanol, in order to prevent contamination from one hole to the next.

vi) Samples were taken back the laboratory where they were tested for faecal coliforms.

Figure 2: In the foreground a completely sealed off monitoring well can be seen. In the background the earlier version of the monitoring well can be seen. This was sealed with an end cap which was locked in place. However, it was later felt that the opening for the lock exposed the monitoring well to the risk of contamination (from, for example, small animals).

<u>Monitoring Family Tube and Ring Wells</u>

(The preparations and testing were done in the same way as above).

- Five to six buckets of water (25-30 litres in total) were bailed from tube wells before a sample was taken.
- The sample was taken using the home owner's bucket.
- The sample was then poured into a sterile sampling bottle and placed in a cool box.
- Samples taken from ring wells were taken straight from the well using what ever bucket was used by the family or community for drawing water.

5. RESULTS

5.1 Travel of Faecal Coliforms from Pit Latrine Monitoring Site

Figure 3 below shows the faecal coliform counts per 100 millilitres of sample at various distances from the pit latrine, in the direction of water flow. Counts of more than 10/100 ml were not observed except at the point one metre from the pit latrine. In terms of contamination, a count of 10 or less faecal coliforms per 100 ml is low, and may be attributable to experimental error. Other samples taken during the winter months (not shown in the figure) had even lower counts. A background sample located 90 metres from the pit latrine perpendicular to the direction of groundwater flow typically registered no faecal coliforms.

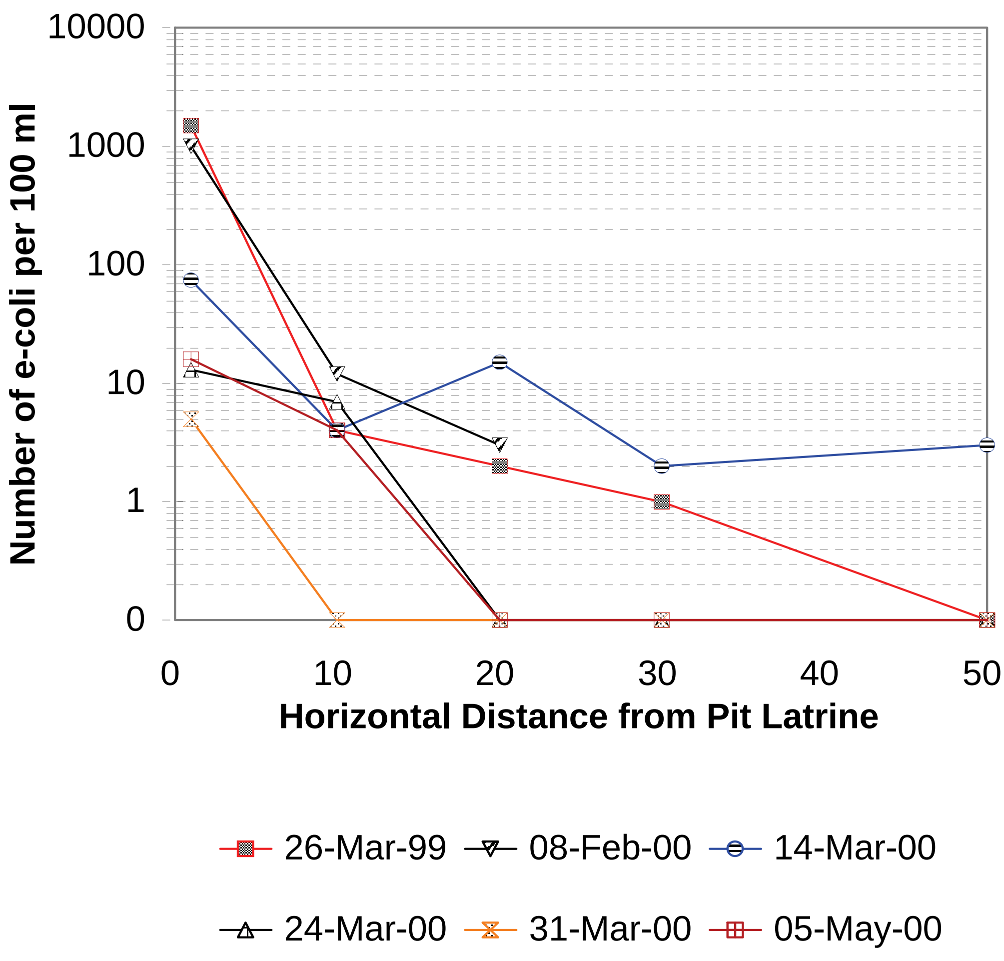

Figure 3: Incidence of faecal coliform in the groundwater at increasing distance from a pit latrine built in 1995 (Site E3 – George Ncube).

5.2 Effect of Pit Latrine on Nitrate Concentration in the Soil

A number of samples from the monitoring holes around the same pit latrine were sent away for nitrate analysis. Mostly the results (see Figure 4 below) indicate an elevated level of nitrates close to the pit latrine, although it is noteworthy that even as close as one metre to a five year old pit latrine the levels are still within acceptable health limits. The samples taken on 26 May 1999 show an anomaly at 50 metres, but this may be due to experimental error. Background samples were taken at 90 metres from the latrine perpendicular to the groundwater flow direction, and the nitrate levels were found to be low (the mean from three samples was 0.79 mg/l as N).

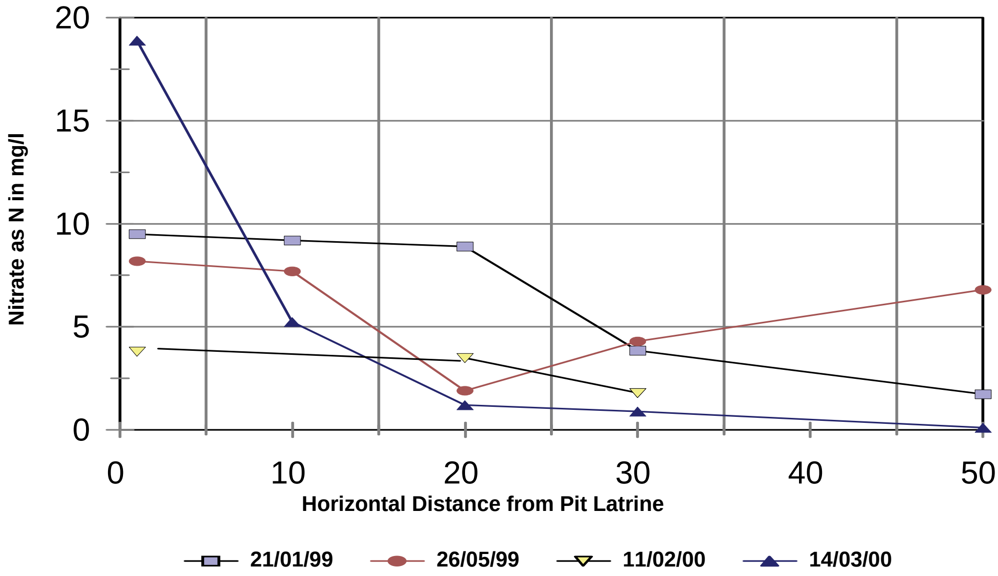

Figure 4: Observations of Nitrate level in monitoring wells near a five year old pit latrine (Site E3)

5.3 Nitrate Levels in Groundwater in the Region

During November 2001 a researcher from the groundwater programme of the CSIR, Stellenbosch, spent a month with Partners in Development at the Mbazwana office, taking water samples from more than fifty wells.

These wells differed in that some were private, while others were shared by ten or more families. Figure 5 shows the range of nitrate (measured as Nitrogen) concentrations observed in these wells. The majority show low levels, and all are within health limits. The higher levels shown in some wells are apparently associated with wells which are used by greater numbers of families. Higher use will tend to cause more water spillage around the well.

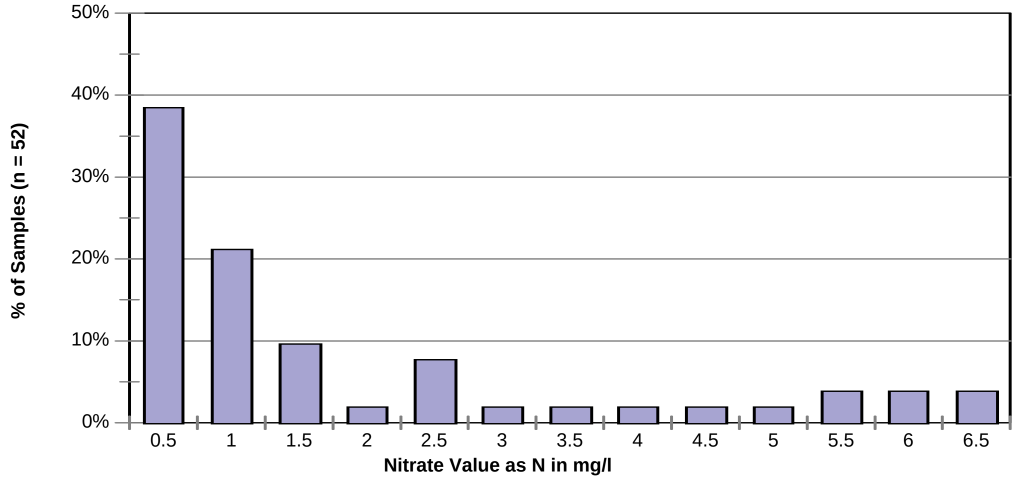

Figure 5: The incidence of Nitrate (measured as Nitrogen in mg/l) in groundwater sources in the Mbazwana area. 52 different water sources were sampled over a one month period in November 2001. The higher nitrates are generally associated with wells where there are more users and therefore more wastage. Levels of below 10 mg/l are acceptable.

This waste water then percolates down to the ground water table, carrying with it nitrates from organics and waste around the well area. A more heavily used well should thus show a higher level of nitrate, so the results make sense. A Hydrogen Sulphide faecal coliform indicator stip test was also done at all the same sites simultaneously, and there appears to be little correlation between those wells which did show some presence of coliforms, and those which had high nitrates. The sand around the well is fine and acts as an effective filter against bacteria. The bacteria observed in the wells (refer to section 4.4) may be introduced by the users from above, rather than being present in the groundwater.

5.4 Observations of Faecal coliforms in Public and Private Wells

The fourth element of this research has been to test private and public wells for faecal coliform bacteria. Over a period of two years thirteen wells have been monitored. These have included the following:

- three protected public tube wells
- three protected private tube wells
- three protected private ring wells
- two protected public ring wells
- two unprotected public ring wells

The manner in which the wells are constructed and protected is described in more detail in Still and Nash (2002).

In all wells bacterial concentrations are in general higher in the warmer summer months. Average concentrations in the protected private tube wells are very low, whereas the concentrations in the public tube wells are somewhat higher. An extract from the data is shown graphically in Figure 6 below.

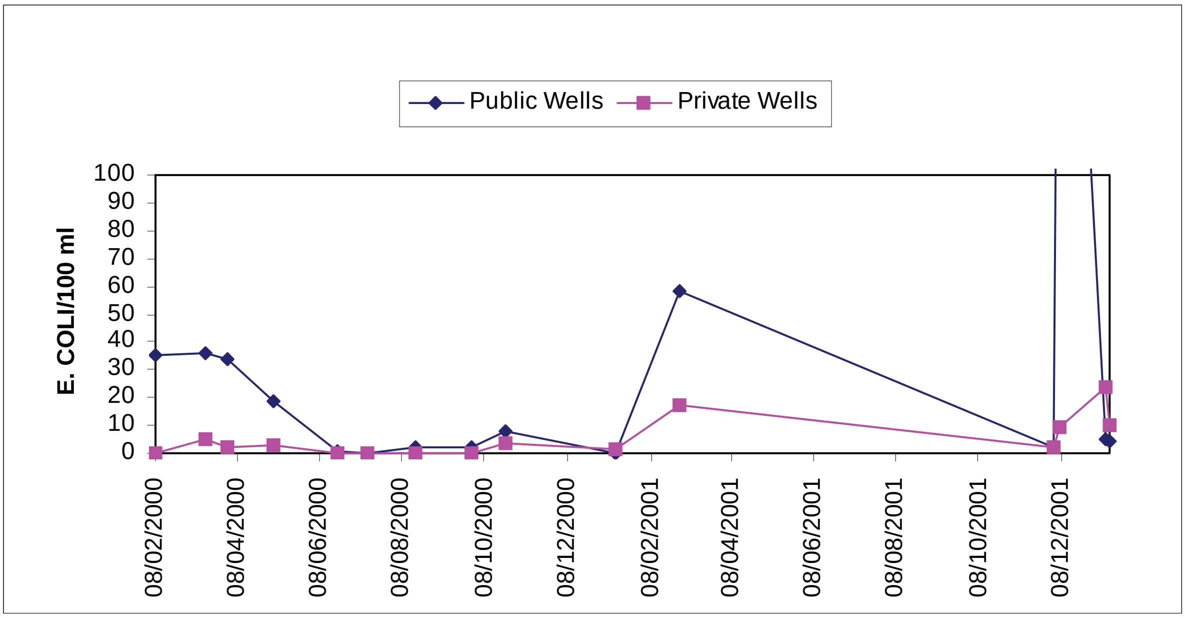

Figure 6: Incidence of Faecal Coliforms in Protected Private and Public Wells (average of readings from three sites each)

As can be expected, the *E. coli* count in the unprotected public wells is much higher. For example, one *unprotected* public well had counts of above 10 000 *E. coli*/100 ml on four of the nine occasions on which it was sampled. Another partially protected public well had much better quality.

The results show that the water quality in protected wells is much better than that in unprotected wells, and that similarly the water quality in private wells is better than that in public wells.

6 CONCLUSIONS

The evidence from this case study demonstrates that the fine sand of this region is an effective filter with regard to bacteria and that pit latrines do not appear to pose a major threat to the contamination of ground water in Maputaland.

With regard to nitrate contamination, pit latrines and public water points do influence nitrate concentrations in the ground water. The effects are, however, localized and not significant from a public health point of view.

Water quality in protected family wells is found to be good, while shared community wells, particularly the older unprotected wells, show signs of contamination.

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