An assessment of water quality in the Inadi ward, Vulindlela district, KwaZulu

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Abstract

An assessment of rain water, ground water and surface sources of water, in terms of selected bacteriological and chemical variates, was conducted in the peri-urban/rural Inadi ward, Vulindlela district of KwaZulu, South Africa. The survey showed that no problems are likely to be encountered in terms of chemical potable standards, although for bacteriological requirements, untreated surface water sources were not acceptable. Unprotected and protected springs were found to yield a markedly better bacteriological grade of water by comparison with surface sources, while roof runoff and a borehole provided the best bacteriological water quality. The data also showed that spring protection results in water of a significantly higher bacteriological grade by comparison with unprotected springs. Protection is accordingly, if correctly applied, an accepted treatment for the upgrading of spring-water supplies. There was some evidence that rain water stored in zinc-lined containers, whether open or enclosed, was of an improved bacteriological quality in terms of non-zinc rain-water vessels. Protected springs, roof runoff and boreholes, therefore, could serve as intermediate sources of potable water in the ward, until formal treated reticulated supplies are established.

Introduction

The peri-urban/rural Inadi ward, Vulindlela district of KwaZulu, is located in a high rainfall area, south-west of Pietermaritzburg. The ward has a mean annual rainfall of the order of 931 mm, 78% of which falls in the months October to March (Alcock, 1984). The upper reaches of the ward form part of the Natal Mistbelt, classified as bioclimate group 3 (Phillips, 1973), with elements of group 4 (Highland Sourveld) and group 6 (Moist Tall Grassveld) vegetation also present. The topography of the study area is steep and rugged with less inclined terrain, largely confined to the crests of hills and the valley bottoms. Predominant soils are the Farningham and Doveton series of the Hutton form with Clovelly, Dundee and Mispah series soils also evident (Fey, 1982). The area is drained by the Msunduze River and three major tributaries, the Msindusaan, Tenjaan and Gezubuzo Rivers (Figure 1). The Msindusaan River is impounded by the small Msindusaan Dam, which, with the downstream confluence of the Tenjaan River, drains into Henley Dam, located on the Msunduze River. Henley Dam is used as a partial supply source for Pietermaritzburg.

The Inadi ward is settled by 30 700 people with an annual population growth rate of approximately 5% (Bromberger, 1985). The major source of potable water is unprotected and protected springs (Alcock, 1984). Protection of a spring (implying the elimination of surface contamination) involves excavation of the eye and the erection of a V-shaped concrete retaining wall, with an attached polyethylene outlet pipe. The chamber is then backfilled with graded rubble and soil and should be grassed and fenced to prevent the ingress of livestock and possible faecal contamination. Rain water is also used as a source of high grade water, although present systems are inefficient with very limited storage. Rivers and dams are used as bulk sources for general household and stock watering requirements. Sanitation in the ward is limited to pit latrines and the very occasional septic tank.

A chemical and bacteriological survey involving roof runoff, springs and a borehole as well as rivers and dams was undertaken, with the objective of future upgrading of supplies for potable and other needs, in the Inadi ward. An important aspect of the research was to establish the effect of treatment, namely protection, on the bacteriological water quality (potability) of springs. Since one objection by residents, to the current use of rain water for potable purposes, is the expressed presence of organic matter in the mostly open household tanks (220ℓ steel drums), total viable organisms as a specific rain-water variate were compared with the same variate for unprotected and then protected springs to assess bacteriological implications. Chemical variates were also examined in terms of potable requirements, as well as given ions present in stored rain water.

Materials and methods

Bacteriological samples were obtained on a weekly basis with chemical sampling undertaken on a monthly basis. The Msunduze, Msindusaan, Tenjaan and Gezubuzo Rivers as well as the Msindusaan and Henley Dams (Figure 1) were selected as representative of rivers and dams in the ward respectively. Survey springs were determined via a 101- reconnaissance sample of springs, in terms of a random sample. Seven unprotected springs (UN1-UN7) and eight protected springs (P1-P8) were so derived. Of the protected sources, springs P1, P4, P6, P7 and P8 had concrete reservoirs, with spring P2 discharging into a partly submerged open, 220ℓ steel drum. Protected springs P3 and P5 were without any form of storage. (Location of the springs is shown in Figure 1). The borehole (B1) briefly sampled in terms of bacteriological variates, was the only such facility in the ward and became inoperative two weeks after sampling began.

Individual sample roof systems were obtained using the technique of areal point sampling by random numbers, yielding four household systems and one school system (Figure 1). All rain systems were fitted with galvanised iron roofs, which with one exception, had not been painted. One unit, namely (T5), had a very old painted roof. Except for unit T1, with PVC gutters, all other systems employed galvanised guttering. Storage facilities involved one enclosed steel ex-farm petrol tank (T1), a commercially available galvanised metal tank (T2), an open steel drum (T3), an open galvanised metal drum (T4) and another open steel drum (T5). Both the drums at units T4 and T5 were rusted to some degree.

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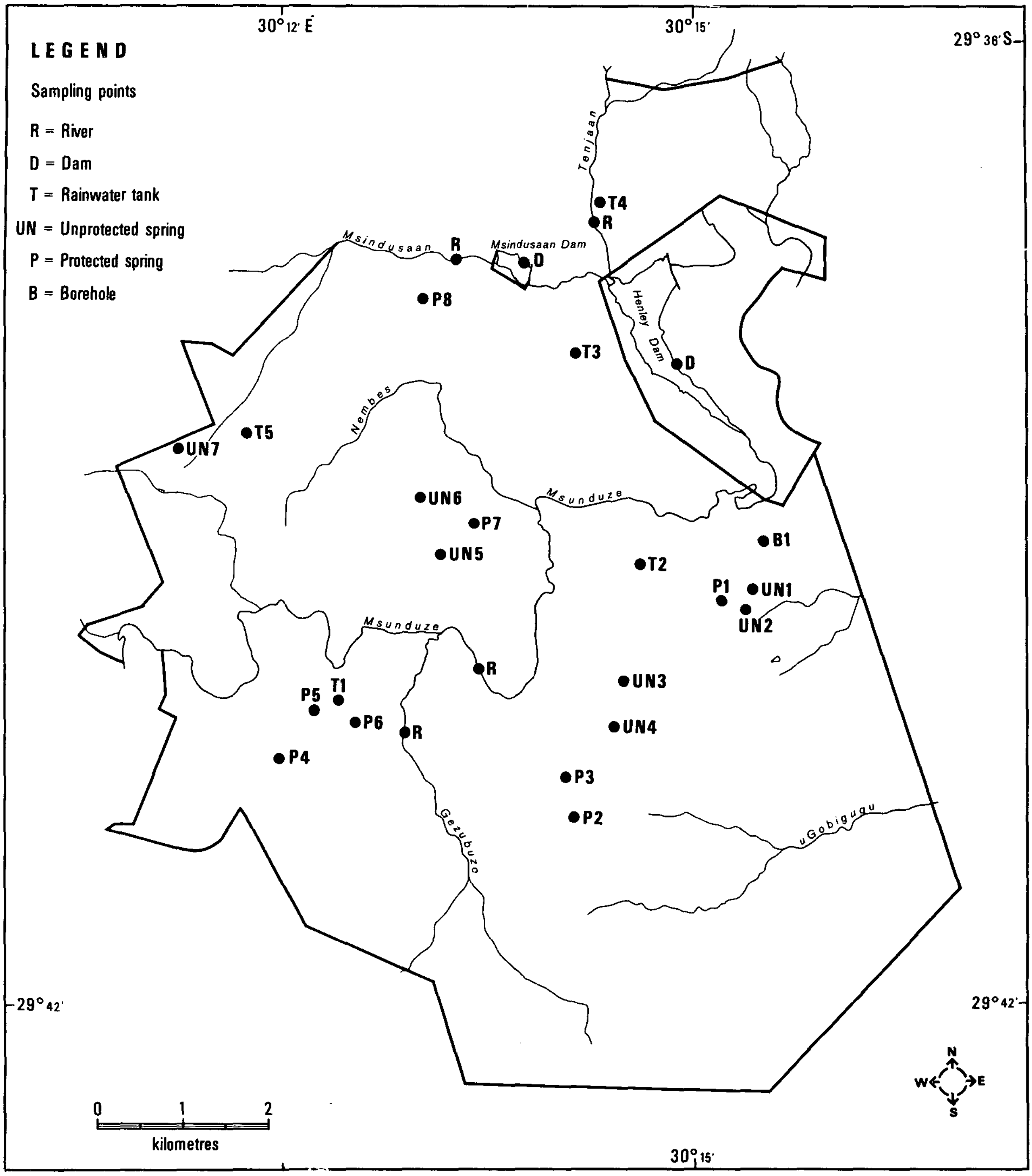

Figure 1
The location of the study area, with sampling points

Bacteriological samples were derived in accordance with South African Bureau of Standards (1971) potable specifications. Variates examined were (total) coliform organisms, *E.coli* I organisms and total viable organisms. Samples were tested in accordance with the SABS (1971) standard procedures. The membrane filtration method was used for coliform and *E.coli* I bacteria. The agar used was m-Endo LES (coliforms) while m-FC agar and m-Endo LES agar was used for *E.coli* I organisms in river/dam and spring/rain-water samples respectively. The presence of *E.coli* I bacteria was confirmed using the indole test. Plate count agar was used for the total viable organisms, which were incubated and enumerated in accordance with SABS (1971) methods. The total viable organisms variate is indicative of bacteria largely derived from soil, dust and sewage plus other organic matter (Grabow, 1970). The variate was used as a test of the general state of hygiene and cleanliness of the water, with special reference to rain water, given perceptions of some local residents regarding the suitability of rain water for drinking purposes. For statistical purposes, the bacteriological data were assessed in terms of the frequency of non-zero values for coliform and *E.coli* I organisms 100 $m\ell^{-1}$ respectively, as well as the frequency of values exceeding 100 total viable organisms colonies mℓ$^{-1}$. Such criteria were derived from the SABS potable standards (1971). The chi-squared test was used in the statistical analysis.

Chemical variates assessed were pH, electrical conductivity (EC) and total dissolved solids (TDS). The pH and electrical conductivity were measured using a Beckman Phasar-1 pH meter and a Radiometer CDM 80 conductivity meter respectively. Individual EC (25 °C) values were multiplied by 6,01 (incorporating a value of 6,7 applicable to Natal waters – as suggested by Kemp (1983), reduced by a temperature correction factor) in order to derive TDS data. The TDS values were each rounded to the nearest whole number. A selected ionic analysis of rain water was undertaken by the Department of Agriculture and Water Supply, Cedara, according to standard methods (APHA, 1981). Historical chemical data quoted in the text and derived by the Pietermaritzburg Municipality, were also assessed in terms of standard methods (APHA, 1965).

Results

Rivers and dams

Chemical data

In terms of the data for chemical variates (Table 1), mean pH, EC and TDS values respectively were similar, where the Tenjaan River recorded the lowest pH and the highest EC and TDS levels with the Gezubuzo River achieving the highest pH value.

With respect to dams, fieldwork chemical data are illustrated in Table 2. Mean pH values are compatible with river data, while the EC and TDS values of the dams were generally lower than fieldwork river data. Comparing the two dams only, variate values were marginally higher in Henley Dam; the largest mean difference noted was a 10 mg.ℓ$^{-1}$ increase of TDS in the major dam. Periodically marked, surface turbidity values (as observed) were a feature of both dams.

Bacteriological data

The bacteriological variates for the four rivers examined in the fieldwork are summarised in Table 3. There was a considerable range in *E.coli* I values between the four rivers (Table 3), with the Gezubuzo River providing the lowest count in contrast with the Tenjaan River with a very high count. The lowest and highest coliform counts were evident in the Gezubuzo and Tenjaan Rivers. The Tenjaan River once again exhibited the highest count for total viable organisms. Both dams (Table 4), in comparison with the rivers, showed reduced bacteriological variate values.

Springs and the borehole

Chemical data

Only two bacteriological samples were derived from the borehole and no chemical variates were examined. Chemical data relating to springs, both unprotected and protected are presented in

TABLE 1
CHEMICAL DATA DETERMINED FOR RIVERS IN THE INADI WARD, VULINDLELA DISTRICT, KWAZULU
(1982-10-11 to 1983-12-12)

Source	Number of samples	pH Mean	pH Range	EC mS.m^{-1} Mean	EC mS.m^{-1} Range	TDS mg.ℓ$^{-1}$ Mean	TDS mg.ℓ$^{-1}$ Range
Msunduze River	15	7,0	6,4-7,5	11,1	8,7-16,5	67	52- 99
Msindusaan River	15	7,0	6,6-7,2	8,0	6,3-12,8	48	38- 77
Tenjaan River	15	6,8	6,5-7,0	12,5	8,8-21,4	75	53-129
Gezubuzo River	15	7,2	6,9-7,6	11,2	8,4-19,9	67	50-119
Mean		7,0		10,7		64	

TABLE 2
CHEMICAL DATA DETERMINED FOR THE MSINDUSAAN AND HENLEY DAMS, INADI WARD
(1982-10-11 to 1983-12-12)

Source	Number of samples	pH Mean	pH Range	EC mS.m^{-1} Mean	EC mS.m^{-1} Range	TDS mg.ℓ$^{-1}$ Mean	TDS mg.ℓ$^{-1}$ Range
Msindusaan Dam	15	6,9	6,6-7,2	8,1	5,9-15,3	49	36-92
Henley Dam	15	7,1	6,8-7,2	9,8	7,8-18,0	59	47-108
Mean		7,0		9,0		54	

TABLE 3
BACTERIOLOGICAL DATA DETERMINED FOR THE MSUNDUZE, MSINDUSAAN, TENJAAN AND GEZUBUZO RIVERS, INADI WARD
(1982-10-11 to 1983-02-07)

		VARIATE					
		Coliform organisms number 100 $m\ell^{-1}$		*E.coli* I number 100 $m\ell^{-1}$		Total viable organisms colonies $m\ell^{-1}$	
Source	Number of samples	Mean	Range	Mean	Range	Mean	Range
Msunduze River	18	10 100,0	2 700-17 000	4 072,2	700-9 000	364,4	90-1 100
Msindusaan River	18	12 022,2	4 200-22 000	5 427,8	2 900-9 000	472,2	220-640
Tenjaan River	18	66 550,0	11 000-480 000	22 750,0	4 300-120 000	2 038,9	320-13 000
Gezubuzo River	18	9 866,7	7 000-16 000	3 572,2	2 100-4 500	372,8	260-600
Mean		24 634,7		8 955,6		812,1	

TABLE 4
BACTERIOLOGICAL DATA DETERMINED FOR THE MSINDUSAAN AND HENLEY DAMS, INADI WARD
(1982-10-11 to 1983-02-07)

		VARIATE					
		Coliform organisms number 100 $m\ell^{-1}$		*E.coli* I number 100 $m\ell^{-1}$		Total viable organisms colonies $m\ell^{-1}$	
Source	Number of samples	Mean	Range	Mean	Range	Mean	Range
Msindusaan Dam	18	1 346,7	600-7 200	297,4	65-1 800	81,3	40-180
Henley Dam	18	1 465,6	120-8 600	454,1	40-4 300	110,9	25-650
Mean		1 406,1		375,8		96,1	

TABLE 5
CHEMICAL DATA DETERMINED FOR UNPROTECTED AND PROTECTED SPRINGS, INADI WARD
(1982-09-06 to 1983-12-12)

		VARIATE					
		pH		EC $mS.m^{-1}$		TDS $mg.\ell^{-1}$	
Source	Number of samples	Mean	Range	Mean	Range	Mean	Range
Unprotected springs							
UN1	16	7,1	6,7-7,3	11,7	10,9-12,4	70	65- 75
UN2	16	6,3	6,2-6,4	8,2	7,1-11,8	49	43- 71
UN3	16	6,3	6,1-6,7	9,9	8,1-15,5	60	49- 93
UN4	16	6,7	6,4-7,1	6,4	5,0-16,6	38	28-100
UN5	16	6,9	6,6-7,2	6,7	5,3-13,3	40	32- 80
UN6	16	6,9	6,6-7,1	8,7	7,8-10,5	52	47- 63
UN7	16	6,6	6,3-7,1	12,1	10,3-16,2	73	62- 98
Mean		6,7		9,1		55	
Protected springs							
P1	16	6,6	6,3-6,9	10,4	9,5-13,1	63	57-78
P2	16	6,7	6,4-6,9	7,8	6,6-13,3	47	40-80
P3	16	6,6	6,3-6,8	9,4	7,8-12,9	56	47-77
P4	16	6,9	6,5-7,2	6,5	5,4-13,7	39	33-82
P5	11	6,7	6,4-7,0	8,5	7,8- 9,1	51	46-55
P6	16	6,7	6,4-6,9	10,6	9,6-14,4	64	58-87
P7	16	7,1	6,9-7,4	14,0	10,6-15,5	84	64-93
P8	16	6,6	6,3-6,9	6,3	5,3-10,2	38	32-61
Mean		6,7		9,2		55	
Overall mean		6,7		9,1		55	

Table 5. Unprotected springs varied between pH 6,3 to 7,1 while protected springs provided a slightly smaller range of 0,5 units. In terms of EC, both unprotected and protected springs displayed low values. The TDS values in springs were also low with a mean of 55 mg.ℓ^{-1}.

In comparison with river and dam chemical variates, spring-water pH values are lower, although the difference is limited. The EC and TDS mean values likewise, are marginally lower. Turbidity was variable in unprotected springs with open pools and was dependent on factors such as human and stock traffic. Protected springs with concrete reservoirs were not turbid (springs P1, P4, P6, P7, P8), which also applied in the case of protected springs without concrete reservoirs (springs P2, P3 and P5).

Bacteriological data

Data relating to bacteriological variates in respect of coliforms, *E.coli* I and total viable organisms, for unprotected and protected springs, are shown in Table 6. The mean coliform count for unprotected springs was nearly double the count for protected springs. The same trend was evident for *E.coli* I organisms. Total viable organisms in both unprotected and protected springs by contrast were reasonably high, although protected springs again recorded the lowest mean value. Both spring sources exhibited much lower coliform and *E.coli* I counts than rivers and dams, although total viable organism data are roughly comparable with the exception of the Tenjaan River. No coliform and *E.coli* I organisms were found in the borehole (two samples only), although the total viable organism count varied between the two samples with values of 118 and 912 colonies mℓ^{-1} respectively.

Rain-water systems

Chemical data

Chemical data for the five rain-water systems are provided in Table 7. The mean pH values varied from 6,4 to 6,7 which is comparable with surface and spring-water sources, although generally slightly lower. Both mean EC and TDS values were also less than the other sources, especially in the case of unit T5. While turbidity was often absent from the individual rain-water tanks sampled, organic matter was sometimes observed.

The highest ionic concentrations noted in rain water were zinc and iron (Table 8), although sodium and calcium levels were also comparatively high. Concerning zinc ions only, units T2 and T4 reflect their materials composition, with a similar trend for iron in T1, T3 and T5. The one-sample data would have to be confirmed in the longer term, given that the survey was essentially a first approximation.

Bacteriological data

Bacteriological variate data for rain-water sources are shown in

TABLE 6
BACTERIOLOGICAL DATA DETERMINED FOR UNPROTECTED AND PROTECTED SPRINGS, INADI WARD
(1982-08-16 to 1983-10-10)

		VARIATE					
		Coliform organisms number 100 mℓ^{-1}		*E.coli* I number 100 mℓ^{-1}		Total viable organisms colonies mℓ^{-1}	
Source	Number of samples	Mean	Range	Mean	Range	Mean	Range
Unprotected springs							
UN1	60	21,8	0-104	12,3	0-98	182,6	2- 768
UN2	60	16,1	0- 90	8,8	0-58	498,2	52-2 040
UN3	60	18,4	0- 63	9,8	0-40	269,3	4- 920
UN4	60	20,2	0-130	10,6	0-100	343,6	16-1 130
UN5	60	16,1	0- 70	8,3	0-63	345,8	62-1 048
UN6	60	19,4	0-130	10,5	0-80	295,4	40-1 020
UN7	60	21,7	0-150	10,8	0-59	358,0	88- 900
Mean		19,1		10,2		327,5	
Protected springs							
P1	60	12,0	0- 40	5,8	0- 35	195,2	14- 800
P2	60	16,1	0- 70	8,0	0- 44	292,1	16- 848
P3	60	12,3	0- 50	5,0	0- 30	210,0	14- 568
P4	60	9,2	0-130	5,5	0-112	127,0	0- 880
P5	42	8,1	0- 60	4,0	0- 29	352,8	0-2 400
P6	60	8,1	0- 43	3,2	0- 21	127,6	10-1 192
P7	60	8,5	0- 50	4,8	0- 45	146,1	4- 780
P8	60	10,2	0- 75	4,3	0- 48	151,2	0-1 240
Mean		10,7		5,2		195,4	
Overall mean		14,5		7,4		259,7	

TABLE 7
pH, EC AND TDS DATA RELATING TO INDIVIDUAL RAIN-WATER SYSTEMS, INADI WARD
(1982-09-06 to 1983-12-12)

Source	Number of samples	pH Mean	pH Range	EC $mS.m^{-1}$ Mean	EC $mS.m^{-1}$ Range	TDS $mg.\ell^{-1}$ Mean	TDS $mg.\ell^{-1}$ Range
T1	14	6,6	6,3-6,9	6,4	2,5-13,0	38	15- 78
T2	16	6,7	6,3-6,9	5,1	3,1-11,2	31	19- 67
T3	13	6,6	6,2-6,8	10,7	4,1-31,8	64	25-191
T4	16	6,5	6,3-6,9	5,6	2,0-11,8	34	12- 71
T5	14	6,4	6,1-6,6	4,2	1,6- 6,2	25	10- 37
Mean		6,5		6,3		38	

TABLE 8
A SELECTED IONIC ANALYSIS OF STORED RAIN WATER, INADI WARD DERIVED ON 1983-10-10

Source	Ca $mg.\ell^{-1}$	Mg $mg.\ell^{-1}$	Na $mg.\ell^{-1}$	K $mg.\ell^{-1}$	Zn $mg.\ell^{-1}$	Fe $mg.\ell^{-1}$	EC $mS.m^{-1}$
T1	1,43	0,10	1,05	0,51	0,10	2,81	7,16
T2	0,60	0,12	1,38	0,39	6,40	1,68	4,19
T3	1,95	0,13	1,13	0,42	0,11	2,55	4,70
T4	1,97	0,25	1,75	3,05	3,90	0,20	2,74
T5	1,29	0,14	1,49	0,46	0,12	2,38	3,64
Mean	1,5	0,15	1,4	1,0	2,1	1,9	4,5

TABLE 9
BACTERIOLOGICAL DATA FOR FIVE RAIN-WATER SYSTEMS, INADI WARD
(1982-08-30 to 1983-10-24)

Source	Number of samples	Coliform organisms number 100 $m\ell^{-1}$ Mean	Coliform organisms number 100 $m\ell^{-1}$ Range	*E.coli* I number 100 $m\ell^{-1}$ Mean	*E.coli* I number 100 $m\ell^{-1}$ Range	Total viable organisms colonies $m\ell^{-1}$ Mean	Total viable organisms colonies $m\ell^{-1}$ Range
T1	49	4,7	0-48	1,9	0-28	332,2	4-1 330
T2	59	1,0	0-18	0,5	0-16	26,1	0- 512
T3	46	7,0	0-45	2,7	0-27	419,3	0-1 030
T4	60	0,5	0-10	0,3	0-5	202,4	0- 880
T5	49	11,2	0-75	4,3	0-32	324,7	0-2 030
Mean		4,9		1,9		260,9	

Table 9. Mean coliform and *E.coli* I counts were low even by spring standards, with especially low counts for T2 and T4. The total viable organism values are generally compatible with springs and some surface sources. A low mean value for total viable organisms in rain-water unit T2 was also evident.

Water source comparisons

With respect to the bacteriological effectiveness of spring treatment, namely protection, protected springs yielded a significantly better grade of water in terms of coliforms, *E.coli* I organisms and total viable organisms, than unprotected springs (Table 10). A comparison of rain water and spring water revealed that rain water was of a significantly better standard than spring water in terms of coliforms and *E.coli* I organisms. However, the two sources did not differ with respect to total viable organisms, where the chi-squared statistic was not significant.

With regard to total viable organisms only, rain water was of a better grade than unprotected springs, although water derived from protected springs was of a higher standard than rain water in terms of the given variate (Table 10). Inspection of Table 9 reveals that rain-water tanks T3, T4 and T5 all with open 220ℓ storage drums, provide some evidence of a trend. System T4, in terms of all three bacteriological variates, yielded water of a markedly better grade in comparison with units T3 and T5.

TABLE 10
STATISTICAL COMPARISONS OF BACTERIOLOGICAL DATA FOR WATER SOURCES IN THE INADI WARD

Source comparisons	d.f.	Chi-squared statistic	Significance level
Unprotected v. protected springs			
Coliform organisms	1	20,73	**
E.coli I	1	30,47	**
Total viable organisms	1	74,87	**
Rain water v. springs			
Coliform organisms	1	253,23	**
E.coli I	1	234,82	**
Total viable organisms	1	0,96	NS
Rain water v. unprotected springs			
Total viable organisms	1	34,37	**
Rain water v. protected springs			
Total viable organisms	1	11,45	**

** = Significant at the 99% level (p = 0,01)
NS = Not significant
d.f. = Degrees of Freedom

Discussion

Rivers and dams

Chemical variates

A previous survey of the Msunduze River (Brand *et al.*, 1967), showed that water of the river was of the Class II category, as defined in their report. Historical data derived for the Msunduze, Msindusaan and Tenjaan Rivers in the period 1963 to 1977 (Pietermaritzburg Municipality, 1983) revealed mean pH values for the three rivers of 7,2; 7,2 and 7,1 respectively. The mean EC values were 6,9; 5,4 and 6,9 $mS.m^{-1}$ with mean TDS values of 42; 33 and 42 $mg.\ell^{-1}$ respectively. The overall mean values were pH 7,2; EC 6,4 $mS.m^{-1}$ and TDS 12 $mg.\ell^{-1}$ (Pietermaritzburg Municipality, 1983). Given data derived by Brand *et al.* (1967), as well as the Pietermaritzburg Municipality data and the present fieldwork sample, it is not unreasonable to state that the chemical water quality of rivers in the Inadi ward, has remained relatively unchanged, in the absence of any industrial input. Referring to sediment, Wylie (1965) found that the mean monthly suspended sediment load in the Msunduze River on entry to Henley Dam was 890 t, with both Wylie (1965) and Archibald *et al.* (1980) observing a marked seasonal fluctuation in the load, reaching a maximum during the summer months. It is quite possible following further population immigration and growth in the Vulindlela district, that sediment yields will increase.

With respect to Henley Dam itself, Archibald *et al.* (1980) found pH values ranging from 6,7 to 7,9 with EC varying from 4,1 to 9,1 $mS.m^{-1}$. Archibald *et al.* (1980) noted that the dam has a high flushing rate, especially during summer, which helps to offset variate loads. Based on fieldwork data, Pietermaritzburg Municipality records and work undertaken by Archibald *et al.* (1980), it is apparent that the chemical quality of the various surface water sources in the Inadi ward, with the exception of turbidity levels (Archibald *et al.*, 1980), meets the recommended SABS (1984) limits for potable water.

Bacteriological variates

Historical bacteriological data derived by the Pietermaritzburg Municipality (not shown in Table 3), in terms of the tube method (Pietermaritzburg Municipality, 1983) which are not compatible with the membrane filtration method, serve to demonstrate changes in water quality ranking over time in terms of the *E.coli* I variate. The relative values of Pietermaritzburg Municipality sample rivers (excluding the Gezubuzo River) in the period 1963 to 1977 with respect to *E.coli* I organisms, from highest to lowest count, was the Tenjaan, Msunduze and Msindusaan Rivers. The Tenjaan River, with reference to *E.coli* I (Table 3), has remained the worst source, while historical data show the Msindusaan River to be of a slightly better grade than the Msunduze River. However, the more recent data show a reversal, with the Msunduze River yielding lower mean *E.coli* I counts.

The bacteriological river-water quality (Table 3) is far in excess of the SABS (1984) potable specifications, although no maximum allowable limit is laid down for total viable organisms. The relevant specifications are:

- coliform organisms 100 $m\ell^{-1}$ – recommended limit 0, maximum allowable limit 5;
- *E.coli* I organisms 100 $m\ell^{-1}$ – both recommended and maximum allowable limits 0;
- total viable organisms – recommended limit 100 colonies $m\ell^{-1}$.

Both dams fail to meet coliform and *E.coli* I potable specifications, although the total viable organisms count for the Msindusaan Dam is within the recommended limit and is marginally above the same limit in Henley Dam (Table 4). Henley Dam had higher variate counts, which is probably due to the effective contribution of the sub-catchment at that point, flushing and dilution factors notwithstanding.

Springs and the borehole

Chemical variates

The chemical quality of spring water, whether unprotected or protected, meets SABS (1984) potable standards (Table 5). The mean study area chemical variate values differ markedly from deeper ground water in arid parts of South Africa where, for example, chloride waters with high sulphates and TDS levels prevail on granite bedrock in the north-western Cape (Bond, 1946). High salinity levels are also evident in the deeper ground water of the Great Fish River Basin (Tordiffe *et al.*, 1985). In more humid areas, in Lesotho for example, Feacham *et al.* (1978) determined pH values similar to the study area in springs and boreholes in rural areas.

Bacteriological variates

Protected springs in Inadi provided water of a considerably better bacteriological water quality than unprotected springs (Tables 6 and 10) in terms of coliform and *E.coli* I organisms, although high total viable organism counts were evident in both sources. Coliform and *E.coli* I bacteria observed in protected springs, are believed to have gained entry via infiltration at the eye, with bacterial counts dependent on several factors such as stock concentration points and spring discharge volume as well as efficiency of the spring protection procedure. Spring P2 with an open 220ℓ partly submerged drum as a storage unit, recorded *E.coli* I levels in accordance with two unprotected springs. The practice of an open storage vessel, to some extent, defeats the objective of protection and cannot be recommended. No unprotected and protected springs meet either the recommended limit or the maximum allowable limit for coliform organisms (SABS, 1984). With respect to the *E.coli* I variate, all springs fall outside both recommended and maximum allowable SABS (1984) limits. Likewise, all springs were unable to meet the recommended SABS limit for total viable organisms (Table 6). The only borehole sampled, while recording no coliform or *E.coli* I organisms, would also not meet the SABS recommended limit for total viable organisms.

In terms of springs and boreholes elsewhere in southern Africa, available water quality data are limited. Friedman (1983) working in a peri-urban/rural area in the Valley of Thousand Hills (KwaZulu), resembling the Inadi ward in part, found that spring protection was a viable means of eliminating or substantially reducing *E.coli* I counts. In Lesotho, Feachem *et al.* (1978) observed that protected springs with storage and reticulation, recorded lower bacterial counts than protected springs *per se* in respect of faecal coliforms and faecal streptococci. Boreholes provided the best grade of water. Feachem *et al.* (1978) found, however, that protected springs did not always yield a higher bacteriological water quality than unprotected springs. They also observed that much of the faecal contamination in springs was of animal rather than human origin.

Rain-water systems

Chemical variates

Rain water, with regard to the three chemical variates (Table 7) was within the SABS (1984) limits, although iron concentrations (Table 8) were slightly in excess of the maximum allowable limit, with the exception of unit T4. Zinc ionic concentrations, except for T2 and T4, were within the SABS (1984) recommended limit, while all units met the maximum allowable limit for zinc, excluding T2. Rain-water storage vessels, except for T2, consisted of redundant containers which were not maintained except for cleaning operations when empty. No difficulties were evident in terms of the 1984 standards, for other rain-water ions tested. The relative importance of calcium and sodium ions in the rain water tested in the Inadi ward, has been noted elsewhere in the vicinity, at Cedara, in the Natal Midlands (Murgatroyd, 1983). With reference to rain-water chemical data from other parts of southern Africa, Gould (1983) in Botswana, found pH for three rain-water systems involving galvanised iron roofs and tanks to range from 6,3 to 7,5 with the EC varying from 0,8 to 10,7 $mS.m^{-1}$.

Bacteriological variates

In terms of coliform and *E.coli* I variates (Table 9), rain water represents the second highest grade of water available in the Inadi ward, with mean *E.coli* I counts especially for units T2 and T4, only marginally above the relevant SABS (1984) specifications. A feature of all sources of water in Inadi, was the relatively high total viable organism counts, which must be expected in an untreated environment. Rain water therefore, provides a better quality of water than both unprotected and protected springs, although differences are evident *vis-a-vis* total viable organisms (Table 10). The view-point of certain residents that rain water *per se* is not safe to drink ("clean") is not substantiated on a long-term basis for the coliform and *E.coli* I variates, with some evidence, if total viable organisms only are examined. Bacteriological data notwithstanding, it is the individual resident's perception of water quality (Alcock, 1985), rather than scientific evidence, which will determine potable consumption of rain water.

With regard to potential pathogenic concentrations, rain *per se* in rural areas has been found to contain a mean count of less than 1 coliform organism 100 $m\ell^{-1}$, although concentrations may be variable (Geldreich *et al.*, 1968). However, faecal matter deposited by birds could lead to contamination of roof runoff. At the same time, the high temperatures obtaining on metal roofs, especially in summer, would result in a rapid desiccation of faeces with consequent bacterial death, unless sufficient rainfall resulting in roof runoff, rapidly flushes faecal matter into the tank. In terms of the roof systems sampled, bird faecal deposition especially in the case of system T2, with an enclosed rain-water tank, thereby excluding the possiblity of direct human contamination, would appear to be evident, given maximum *E.coli* I concentrations. Bird contamination generally would seem to be of minor significance and has a limited effect on water quality, except in the short term. The same conclusion may be reached in respect of human contamination in closed rain-water tanks. The two major potential sources of possible rain-water contamination, therefore, appear to have no major impact on water quality in the long run.

Several factors can influence bacteriological quality once faecal matter or bacteria have been intercepted in the rain-water tank. It may be argued that large rain-water tanks, for a given catchment area, with a greater dilution factor, would reduce bacterial concentrations, providing a better grade of water. Such a trend may hold in the case of systems T1 and T2. Secondly, on an intuitive basis, enclosed tanks which prevent direct human contamination *per se* or the resuspension of any particulate matter, as opposed to open tanks, other factors held equal, represent an improvement, aesthetic factors notwithstanding. Thirdly, tank materials may also play a role in determining bacterial survival via solute concentration within a specified storage interval. In this regard, water drawn from unit T4 provided a better grade of water than units T3 and T5. In the absence of further investigation, it is possible that the reduced coliform and *E.coli* I concentrations in T4 are due to the ionic composition of the water, since rain-water utilisation patterns appeared to be the same at the three households. Specifically, very low zinc ionic levels were noted in T3 and T5 (Table 8). By contrast, relatively high zinc concentrations were evident in T4 and T2, both with low coliform and *E.coli* I counts.

It is postulated that high zinc levels, derived from the zinc protective coat on galvanised tanks, are not compatible with coliform and *E.coli* I survival in unpolluted waters. Zinc has a certain bactericidal effect in higher concentrations for given bacteria (Sykes, 1972), although a number of other bacteria may tolerate various concentrations of zinc (Olsen and Thornton, 1982). Babich and Stotzky (1978) found that the toxicity of zinc ions to *E.coli* I bacteria via inhibition of synthesis of essential materials and cell destruction, was markedly increased in the presence of sodium chloride as well as magnesium ions; a finding supported by Winslow and Haywood (1931). Albright *et al.*, (1972) examined the toxicity of zinc chloride to indigenous bacteria in natural waters and concluded that zinc ions inhibited growth and survival even in low concentrations of 0,1 $mg.\ell^{-1}$. Support for the possible inhibitory effect of zinc ions on certain bacteria, is also provided by dental research (Harrap *et al.*, 1983; Harrap *et al.*, 1984). The effect of zinc ions however, is complex, given interaction with other ions and has not been extensively researched in an aquatic environment (Weatherley *et al.*, 1980).

Further research is necessary and if the toxic effect of zinc on faecal bacteria *inter alia* in galvanised rain-water tanks is confirmed, a powerful argument for the use of galvanised tanks with such an incorporated purification system is apparent. The procedure could possibly be transferred to concrete spring reservoirs with the installation of a galvanised sheet suspended in the water.

Data relating to the bacteriological quality of roof runoff in non-urbanised environments from other parts of the world, are sparse. Nopmongcol (1981) examined roof runoff in Thailand and reported high total coliform counts of up to 2 400 most probable numbers 100 $m\ell^{-1}$ derived from a thatch roof. O'Meara (1982) in the western Caroline Islands, found that in 62% of water samples derived from roofs, no total coliforms were observed, while 25% of roofs provided coliform counts of up to 100 organisms 100 $m\ell^{-1}$, with the remainder exhibiting counts of between 100 to 550 organisms 100 $m\ell^{-1}$. In Botswana, Gould (1983) found nil counts for total coliforms, faecal coliforms and faecal streptococci at three galvanised roof systems and tanks.

Conclusion

Data relating to the chemical and bacteriological quality of rivers and dams, springs and stored rain water, as well as one borehole, for sample sources in the Inadi ward, Vulindlela district of KwaZulu, have been presented. The chemical quality of all sources was good and with the exception of turbidity levels and specified ions, was within the recommended SABS (1984) limits for potable water.

Water from protected springs has been statistically proven, within the context of the Inadi ward, to be of a better bacteriological quality than unprotected springs. It is concluded that protection, within certain constraints, is an effective treatment for the upgrading of spring-water supplies in peri-urban and rural areas. There appears to be some evidence that rain water stored in metal containers lined with zinc, provides an improved bacteriological water quality. If subsequent research establishes such a trend, then commercially available galvanised rain-water tanks, from a bactericidal view-point, would form the optimum storage material although zinc ionic concentrations may slightly exceed potable water standards in selected instances.

In terms of coliform and *E.coli* I bacteriological variates, rivers, followed by dams, unprotected springs, protected springs, rain water and one borehole provide a spectrum of quality, with the borehole yielding the best grade of water. However, the borehole data were confined to two samples only and would need to be confirmed in the long run. With the possible exception of borehole water, all other sources in Inadi would have to be rejected, were the SABS (1984) bacteriological specifications for potable water to be strictly applied.

Given reality in a peri-urban/rural setting, however, potable consumption preferably from protected springs, rain-water systems and boreholes, can be regarded as functional in the interim. The proviso is made that pit latrine siting and hence the possibility of ground-water contamination, must be controlled. Present rejection of the better sources of water in the Inadi ward, would leave no viable alternative other than formal and large-scale reticulation of purified water. Such a goal should form a longer term objective.

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