Operational Paper

The microbiological quality of groundwater-derived drinking water after long storage in household containers in a rural community of South Africa

Maggy N. B. Momba and T. L. Notshe

ABSTRACT

To investigate the effect of long storage and household containers on the microbiological quality of water in a rural community, borehole water from the reservoir and seven standpipes was used. Borehole water was stored for a period of 72 h in household containers (polyethylene-PE and galvanised steel-GS), which are commonly used by the rural community of Mgquba village. Heterotrophic plate count (HPC) and faecal coliform bacteria were used as the main parameters. Standard spread plate procedure and membrane filtration method were used to enumerate HPC and faecal coliform bacteria respectively. The results of this study revealed three factors that affected the microbiological quality of drinking groundwater used by the rural community of Mgquba village: the intake water, the duration of storage and the household container. The initial levels of faecal coliform (range of faecal coliforms: 0.1–2 cfu · 100 ml^{-1} in the reservoir water, 0–57 cfu · 100 ml^{-1} in the standpipe water) and HPC bacteria (average counts: 5 log cfu · ml^{-1} in the reservoir water, 7 log cfu · ml^{-1} in the standpipe water) in both reservoir and standpipe waters far exceeded the limit allowed by the *South African Water Quality Guidelines for Domestic Use* (no risk target water quality range: 0 count · 100 ml^{-1} for faecal coliforms, 0–100 counts · ml^{-1} for HPC bacteria). The persistence of faecal coliforms in polyethylene-stored water was observed after 72 h of storage while their complete elimination in the galvanized steel-stored water occurred after 48 h of storage. *Escherichia coli* was the most dominant faecal coliform found in the initial and stored waters. Although the yield of HPC bacteria increased in water samples during storage in both polyethylene and galvanised steel containers, the microbiological quality of drinking groundwater deteriorated consistently with the length of the storage. Water stored for 72 h displayed a higher yield of HPC (average counts: 7 log–8 log cfu · ml^{-1} in PE-stored water, 6 log–8 log cfu · ml^{-1} in GS-stored water) than the water stored for 48 h or 24 h (average counts: 5 log–8 log cfu · ml^{-1} in PE-stored water, 5 log–7 log cfu · ml^{-1} in GS-stored water). Statistical analysis indicated a significantly higher number of HPC bacteria in the water stored in polyethylene than in the water stored in galvanised steel ($P=0.02$). Significant differences in HPC bacteria were also noted within household container-stored water from standpipes ($P=0.0001$ for PE, $P=0.0002$ for GS).

Key words | groundwater, household containers, microbiological quality, storage

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INTRODUCTION

Water intended for human consumption must be free from organisms and concentrations of chemicals that may be a hazard to health (WHO 1996). Some years ago when populations were low and widely dispersed, there was sufficient drinking water available which did not require treatment. With the explosive population growth of recent

decades, water quality problems have intensified. Most cities, large and small, all over the world have exceeded the forecast demand on their facilities. Consequently, the treatment of drinking water has become a very significant public health measure. Disinfection processes such as chlorination, chloramination, ozonation and UV irradiation are used for the treatment of drinking water.

In South Africa, the availability of safe and clean water seems not to pose any serious problems in towns and cities. Chlorination occupies a key position, as it is indispensable for the prevention or reduction of water-borne infectious diseases. Consumers are constantly supplied with piped treated water of high quality. However, in rural and developing areas, most communities do not have access to safe drinking water. It has been reported that a quarter of South Africa's population (12 million) have no access to safe water (Bailey & Archer 2000). Unavailability or inaccessibility of supplied water in rural areas leads to the direct use of untreated water from rivers, streams, boreholes and other sources for a variety of domestic purposes.

In semi-arid areas such as parts of the Eastern Cape Province of South Africa, groundwater remains the main water supply source for many small communities. Some communities receive their drinking water directly from uncovered or covered boreholes and wells, whereas for others, the water is drawn from the boreholes (using an engine) to a reservoir, and from the reservoir the water is then delivered to the people through a public standpipe system. In both cases, groundwater is distributed to the community without any purification. It is well known that the inadequate design, construction, operation and maintenance of wells and boreholes can lead to quality problems related to groundwater. Poor sanitary sealing is more generally a common cause of microbiological quality deterioration. There are also naturally occurring groundwater problems which can present significant health problems, for example, elevated concentrations of fluoride and nitrate, and others cause taste problems such as high concentrations of iron and manganese (Foster 1995). The failure to periodically drain and clean water supply holding tanks to remove sediments provides opportunities for heterotrophic bacterial colonization and biofilm development. These microbes may cause undesirable taste and odour (Geldreich *et al*. 1972).

A further dimension has been added to the above problem because of the need for rural communities to store water. Due to the long distances between the sources of drinking water and villages, household containers are used for storage. The storage of water at the dwelling, as well as the handling, could lead to a quality unsuitable for human consumption. The deterioration of water quality could result not only from poor household container hygiene and open containers subjected to environmental pollution, but also from the way in which water is handled by individuals in households (Jagals *et al.* 1997). Household containers, which are widely used in rural communities, are made of polyethylene and galvanised steel. It has been noted that a wide range of materials, in particular synthetic materials such as polyvinyl, polyethylene and types of rubber, can promote growth of microorganisms (Momba & Mnqumevu 2000). Van der Kooij & Veedendaal (1994) presented evidence that certain plumbing materials promote growth of *Legionella* species. Therefore, the selection of materials that do not promote growth of microorganisms is essential. This selection strategy could achieve and maintain the biological stability of drinking water (van der Kooij & Veedendal 1994).

The typically long exposure times in household containers can lead not only to taste and odour problems, but also to the further deterioration of the microbiological quality of drinking water. Elevated incidences of infectious diseases like gastroenteritis have been associated with such water supplies. The water provided by the above system can fail to meet drinking water standards without anyone being aware of this fact, as the monitoring programme of the intake water from the groundwater sources, reservoirs as well as the standpipes, remains almost non-existent. This water, therefore, can affect people's health via food production, direct consumption or via hygiene and sanitation.

The lack of direct information on the microbial quality of drinking groundwater before and after storage in household containers used by the rural communities in the Eastern Cape Province of South Africa was the first concern that led to this study. To investigate the effect that long storage and household containers have on the

microbial quality of water in rural communities, borehole water from the standpipes was used. Heterotrophic plate count and faecal coliform bacteria were used as the main parameters with references to the *South African Water Quality Guidelines–Domestic Use* (DWAF 1996). Heterotrophic plate count and coliform bacteria are currently used as bacterial indicators to define the general microbial quality of drinking water and to assess the general hygienic quality of water, respectively (DWAF 1996). Faecal coliforms are used to evaluate the raw water for drinking water supply. The presence of *Escherichia coli* is used to confirm the presence of faecal pollution by warm-blooded animals (often interpreted as human faecal pollution; DWAF 1996).

MATERIAL AND METHODS

Description of the site

Mgquba village is located in a semi-arid rural area, situated about 10 km from Alice town in the Eastern Cape. The community gets its drinking water from a borehole located in Skolweni, about 2.5 km from Mgquba. The water is drawn from a covered borehole using the engine and then pumped into a covered storage tank made of cement (reservoir). From the reservoir, the water is then distributed through the standpipes to the community without any purification. The standpipes are situated on the main road of the village and the distance between the standpipes is approximately 1 km. Seven standpipes were used in this study.

Collection of information

A questionnaire relating to the source of water, household storage container and duration of storage was distributed to 51 houses in Mgquba. Data collected from this questionnaire indicated that approximately 95% of the community use public standpipes to collect the water from the borehole, 78% of the community use polyethylene containers and about 22% use galvanised steel containers to collect and store their drinking water. It was also observed that about 63% of the consumers store their water for about 1 to 2 days, 18% for a few hours (5–12 h), 16% for about 3 days, and about 3% for about 7 days. This study considered a 3-day duration for the storage of water in household containers.

Sampling

To obtain statistically meaningful results, the sampling programme was carried out about once a week for a period of 4 months. Water from the reservoir and standpipes was used in this study. The standpipe was flushed for approximately 5 min before the collection of the sample. Water samples were collected in polyethylene and galvanised steel containers previously rinsed with standpipe water, and the control water was collected in 1-l sterile bottles. Analysis proceeded immediately after collection. No disinfection was performed during the study period.

Microbial analysis

Faecal coliforms were determined according to *Standard Methods* using mFC agar (Biolab) (APHA 1992). All analyses were performed in triplicate. All colonies which conformed to the definition of faecal coliforms were picked from the membranes and purified on mFC agar (Biolab). The IMVC tests (i.e. Indole, Methyl red, Voges and Proskauer, Citrate) and the commercial API 20E system as well as Bergey's manual (Krieg & Holt 1984) were used for the identification of faecal coliforms.

Heterotrophic plate count bacteria were enumerated by the standard spread plate procedure using R2A agar (Difco), incubated at 28°C for 7 days (Reasoner & Geldreich 1985). The spread plate method provides conditions that are more conducive to growth of bacteria in water than the pour plate method. It almost invariably yields higher colony counts than does the poor plate method (Reasoner & Geldreich 1985). Since the present study deals with the effect of long storage on the bacteriological quality of drinking water, this method has the advantage of providing an approximate enumeration of total numbers of viable bacteria that may yield useful information about the quality of groundwater and may also provide supporting data on the significance of coliform test results. R2A agar is therefore recommended as the medium of choice. Results from parallel studies with

spread plate, membrane filter and poor plate procedures showed that R2A agar yields significantly higher bacterial counts than does plate count agar (Reasoner & Geldreich 1985; APHA 1992). A combination of the spread plate method and R2A agar, therefore, defined the general bacterial quality of drinking groundwater and provided information on the general hygienic quality of the drinking water used by the Mgquba community.

Least square of differences (LSD) was used to compare variations in heterotrophic plate count bacteria in polyethylene and galvanised steel containers. The bacteria were used as the dependant variable. The heterotrophic bacterial counts were transformed by taking the logarithm of base 10 in order to stabilize the variance.

Physico-chemical analysis

With the exception of turbidity, pH and temperature, other physico-chemical characteristics (e.g calcium, magnesium, chemical oxygen demand, total nitrogen, phosphate, sulphate and dissolved organic carbon) of groundwater in Mgquba were determined in a parallel study performed by Ndaliso (2001). Table 1 illustrates the average values of these compounds in groundwater samples. These data give general information on the physico-chemical quality of drinking water in Mgquba.

The turbidity, pH and temperature were measured with a Hach 2100P turbidimeter, a micro pH 2000 (Crison) pH meter and a Celsius thermometer respectively. Suspended solids were determined according to *Standard Methods* (APHA 1992). Sample frequency is indicated in the results and is the same for all experiments. Calcium, magnesium, chemical oxygen demand, total nitrogen, phosphate, and sulphate were determined according to spectroquant NOVA 60 (Merck Manuel 1998). Water samples for dissolved organic carbon (DOC) were prepared according to Mathieu *et al.* (1993) and the DOC concentration was measured using an AQUADOC™ TOC analyser based on persulphate-ultraviolet oxidation.

RESULTS AND DISCUSSION

In this study, the bacteriological quality of groundwater was assessed before and after storage in order to determine the effect of the storage process on the microbiological quality of drinking water used by the rural community of Mgquba in the Eastern Cape of South Africa. Faecal coliform and heterotrophic plate count bacteria were used as bacteriological parameters. Results obtained revealed that the general bacteriological quality of the initial drinking groundwater from the reservoir, standpipes and container-stored waters was poor and the water was unsafe for consumption (Tables 2–4).

While lower faecal coliform counts were noted in water from the reservoir and standpipes 2, 4–7, higher levels of faecal coliform were recorded in water from standpipes 1 and 3 (Table 2). Using the *South African Water Quality Guidelines for Domestic Use*, which recommends the maximum acceptable limit for no health risk (DWAF 1996), the levels of faecal coliform exceeded the recommended standard for drinking water (Table 2). The deteriorating standard of groundwater quality in the Mgquba community could be linked to the presence of many pit toilets and farmyards surrounding the village. This study confirms previous investigators who noted similar observations (Chilton *et al.* 1995; Periago *et al.* 2000). According to Chilton and collaborators (1995), farmyards constitute a source of groundwater pollution. The application of cattle slurry as fertiliser is the major cause of diffuse source water pollution in many agricultural regions (Periago *et al.* 2000). Higher concentrations of faecal coliforms in water from standpipes 1 and 3 (average count: $27\ \text{cfu} \cdot 100\ \text{ml}^{-1}$ for Stp 1; $22\ \text{cfu} \cdot 100\ \text{ml}^{-1}$ for Stp 3) might be due to the fact that the sampling of water from both standpipes was done during the rainy period and simultaneously after rainy days. Wierenga (1985) and LeChevallier *et al.* (1991, 1996) have associated the occurrence of coliform bacteria in drinking water systems with rainfall events. Rainfall can be a mechanism that introduces coliform bacteria into the system through leaks and cross connections (Wierenga 1985). According to LeChevallier *et al.* (1996) the occurrence of coliform bacteria increased in water when rainfall levels increased.

Considering the effect of storage and household containers on the bacterial quality of drinking water, results obtained showed a gradual decrease of faecal coliform counts in both types of container-stored water (Table 2).

Table 1 | Physico-chemical characteristics (average values) of borehole water during storage

	Water sample collected from the reservoir						
Parameter	**Control**	**Stored in polyethylene**	**Stored in galvanised steel**				
Turbidity (NTU)	0.39	0.33	1.31				
pH	0.72	8.02	8.23				
T (°C)	20.40	20.04	20.00				
SS (mg/l)	0.03	0.03	0.03				
DOC (mg/l)	6.27	ND	ND				
Ca^{2+} (mg/l)	63.75	ND	ND				
Mg^{2+} (mg/l)	79.83	ND	ND				
N (mg/l)	4.76	ND	ND				
PO_4^{3-} (mg/l)	0.35	ND	ND				
SO_4^{2-} (mg/l)	58.67	ND	ND				
	Water sample collected from the standpipes before storage (control)						
	Stp1	**Stp2**	**Stp3**	**Stp4**	**Stp5**	**Stp6**	**Stp7**
Turbidity (NTU)	0.3	0.3	0.3	0.2	0.2	0.2	0.2
pH	7.8	7.9	7.8	7.9	7.7	7.7	7.7
T (°C)	19.4	20.2	19.0	21.5	21.7	23.6	23.6
SS (mg/l)	0.04	0.03	0.04	0.03	0.03	0.03	0.03
	Water sample collected from the standpipes and stored in polyethylene						
	Stp1	**Stp2**	**Stp3**	**Stp4**	**Stp5**	**Stp6**	**Stp7**
Turbidity (NTU)	0.5	0.3	0.3	0.3	0.3	0.3	0.3
pH	8.0	8.3	8.0	7.9	8.0	8.0	8.0
T (°C)	21.8	20.4	21.2	21.3	21.4	22.7	22.8
SS (mg/l)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Water sample collected from the standpipes and stored in galvanised steel						
	Stp1	**Stp2**	**Stp3**	**Stp4**	**Stp5**	**Stp6**	**Stp7**
Turbidity (NTU)	0.8	0.5	0.3	0.6	0.7	0.8	0.6
pH	8.8	8.3	8.3	8.1	8.2	8.2	8.2
T (°C)	21.3	20.0	21.5	21.4	21.0	22.2	22.3
SS (mg/l)	0.03	0.03	0.03	0.03	0.03	0.03	0.03

SS, suspended solids; T, temperature; DOC, dissolved organic carbon; Stp, standpipe; ND, not done.

Table 2 | Detection of faecal coliform bacteria (average cfu/100 ml) in borehole water during the study period

Initial bacterial counts in water samples before storage (Control—C) in cfu · 100 ml^{-1}									
				Water from standpipes					
No. of samples	Reservoir water			Stp 1		Stp 3		Stp 2, 4–7	
16	Mean	0.07		27		22		0.05	
	Range	0.01–2		0–57		0–47		0.1–0.07	
Bacterial counts during storage									
	Time		**Reservoir water**		**Water from standpipes**				
			PE	**GS**	**PE**			**GS**	
					Stp 1	**Stp 3**	**Stp 2, 4–7**	**Stp 1**	**Stp 3**	**Stp 2, 4–7**
16	24 h	Mean	0.05	0.01	22	14	0.01	5	7	0.01
		Range	0.05–0.1	0	1–42	1–33	0–0.03	1–11	1–21	0–0.05
16	48 h	Mean	0.03	0	17	10	0.01	0	1	0
		Range	0.02–0.05	0	1–43	1–24	0–0.05	0	0	0
16	72 h	Mean	0.01	0	4	8	0.01	0	0	0
		Range	0–0.03	0	1–7	1–43	0.01–0.03	0	0	0

PE, Polyethylene; GS, galvanised steel; Stp, standpipes.

These findings agreed with those of previous investigators who reported that coliform populations in drinking water samples held at 5°C and 22°C declined significantly after 24, 30 and 48 h but not after 2, 6 or 12 h as measured by the membrane filtration and most probable number methods (McDaniels & Bardner 1983). The decline in the number of faecal coliforms might also be due to the depletion of nutrients. Although a gradual decrease was observed in both containers, more faecal coliforms were observed in polyethylene-stored water than in galvanized steel-stored water (Table 2). The persistence of faecal coliforms in polyethylene-stored water was observed 72 h after storage while the complete disappearance of faecal coliforms occurred 48 h after storage of water in the galvanised steel container. The greater persistence of faecal coliforms in polyethylene-stored water could be linked to the fact that polyethylene releases more nutrients than galvanized steel as reported by Momba & Kaleni (2001). The authors indicated that polyethylene released more DOC (11–13 mg $C \cdot l^{-1}$) than galvanized steel (8 mg $C \cdot l^{-1}$) during the process of drinking water storage.

The IMVC tests and API 20E systems used for the identification of faecal coliforms revealed that *Escherichia coli* was the most dominating faecal coliform bacteria found in the borehole water. The presence of *E. coli* confirms the presence of faecal pollution by warm-blooded animals, often interpreted as human faecal pollution (DWAF 1996). Its occurrence during storage is of concern because faecal pathogens such *Salmonella* spp,

Shigella spp., viruses and protozoa may be present. Consequently consumption of water from untreated groundwater may pose a significant health risk. Higher concentrations of faecal coliforms in drinking water will indicate a higher risk of contracting waterborne diseases, even if small amounts of water are consumed (DWAF 1996). As no conventional treatments are practised, the community must be informed about the quality of their drinking water. Practical measures such as boiling of water before use must then be considered.

Results of the present study also revealed that the levels of HPC bacteria in both initial water sources (reservoir and standpipes) were high (Tables 3 & 4, Figures 1–3), and far exceeded the limit allowed by *South African Water Quality Guidelines for Domestic Use* (target water quality range: 0–100 counts $\cdot$ ml^{-1}). High concentrations of HPC bacteria in Mgquba drinking groundwater could lead to a high risk of waterborne disease and pose a health risk as this water is used for domestic consumption. This observation confirmed Momba and co-workers' findings, which pointed out the poor quality of Nkonkobe district groundwater, in the Eastern Cape Province of South Africa (Momba & Mnqumevu 2000). Due to the poor hygienic quality of Mgquba groundwater, it is suggested that this drinking water undergoes some treatment before use.

The general bacterial content of the initial water from the reservoir and standpipes was found to be the major factor contributing to the high level of heterotrophic bacteria in container-stored waters (Table 3, Figures 1–3) although some physico-chemical parameters could also influence the growth of microorganisms during storage (Table 1). Temperature values ranging between 19 and 23°C were recorded in the intake water as well as in the container-stored waters during the study period. Significant microbial activities have been observed in water at 15°C, or higher, by previous investigators (Donlan & Pipes 1988; Donlan *et al*. 1994; LeChevallier *et al*. 1996). According to them, temperature is the most important controlling influence on microbial growth in drinking water and there is little that most water utilities can do to change water temperature. While other factors such as pH, turbidity, suspended solids, sulphate, total nitrogen and phosphate complied with the allowable standards stipulated by the *South African Water Quality Guidelines for Domestic Use* (DWAF 1996), dissolved organic carbon (DOC), calcium and magnesium exceeded the limits. In South Africa, the DOC target water quality ranges between 0 and 5 mg $\cdot$ l^{-1}. However, Joret *et al.* (1991) reported that *E. coli, Klebsiella pneumonia* and *Enterobacter cloacae* can multiply in river water samples with a 3.2 mg $\cdot$ l^{-1} initial DOC concentration, but are not prone to grow in finished water samples with initial DOCs of 0.4 mg $\cdot$ l^{-1} and 0.8 mg $\cdot$ l^{-1}. There is then evidence to suggest that the DOC concentration of 6.3 mg . l^{-1} could influence the growth of bacteria in borehole water from Mgquba village. Moreover, it has been stipulated that the deterioration of water quality could result from household container hygiene and open containers subjected to environmental pollution, as well as from the manner of handling of water by individuals in a household (Jagals *et al.* 1997). However, during the experimental study, the storage of water was aseptically performed in clean household containers. This fact confirms the effect of the quality of intake water on the deterioration of stored water. It is important to note that higher HPC values were recorded in water collected from the standpipes (Figures 2 & 3) as compared to water collected from the reservoir (Figure 1) although prolonged exposure time led to the increase of heterotrophic bacterial counts in both water sources. Moreover, a comparison between the standpipes showed that HPC bacteria in water stored in polyethylene and galvanized steel appeared to differ between the standpipes. Heterotrophic plate count bacterial counts in standpipe 1 were significantly different from HPC bacterial numbers in standpipes 2, 4 and 5 ($P = 0.0001$). HPC bacterial counts in standpipe 2 were also significantly different from HPC bacterial numbers in standpipes 3, 4, 5, 6 and 7 ($P = 0.0001$). There was a significant difference in HPC bacterial numbers found in standpipe 3 from those found in standpipes 4 and 5 ($P = 0.0001$) and also from HPC bacterial counts in standpipe 6 ($P = 0.01$). HPC bacterial counts in standpipe 4 were significantly different from those in standpipe 6 ($P = 0.03$) and standpipe 7 ($P = 0.0001$). Heterotrophic plate count bacteria in standpipe 5 were significantly different from HPC bacteria in standpipe 6 ($P = 0.02$) and from HPC bacteria in standpipe 7 ($P = 0.0001$). The length of pipes could contribute to water quality deterioration

Table 3 | Range of heterotrophic plate count bacteria (log cfu · ml^{-1}) in the reservoir and container-stored waters during the study period

		Water from the reservoir			
	No. of samples	**0 h**	**24 h**	**48 h**	**72 h**
Polyethylene	16	5.7–5.9	5.9–6.9	6.4–7.0	8.0–8.7
Galvanised steel	16	5.6–5.9	5.8–6.1	5.8–7.8	6.5–7.8
		Water from the standpipes (Stp) stored in polyethylene			
	No. of samples	**0 h**	**24 h**	**48 h**	**72 h**
Stp 1	16	6.9–7.7	7.2–8.2	8.0–8.2	8.3–8.5
Stp 2	16	5.4–8.0	6.4–7.7	7.8–8.3	7.6–8.4
Stp 3	16	5.4–8.2	6.3–7.7	7.5–8.2	7.8–8.4
Stp 4	16	7.4–7.6	7.9–8.4	8.4–9.2	8.7–9.6
Stp 5	16	7.4–7.8	7.6–8.3	7.8–9.2	8.6–9.6
Stp 6	16	7.4–7.6	7.9–8.3	7.5–8.5	8.2–8.6
Stp 7	16	6.4–7.7	7.4–8.1	7.9–8.5	8.1–8.5
		Water from the standpipes (Stp) stored in galvanized steel			
	No. of samples	**0 h**	**24 h**	**48 h**	**72 h**
Stp 1	16	7.1–8.9	7.8–8.2	7.8–8.3	8.0–8.3
Stp 2	16	5.2–7.8	5.1–7.9	6.1–6.8	6.4–7.2
Stp 3	16	5.4–8.0	5.3–7.7	7.4–7.9	7.4–7.7
Stp 4	16	7.3–7.5	7.2–7.6	7.9–8.6	7.9–9.3
Stp 5	16	6.8–7.6	7.1–7.5	7.8–8.3	8.8–9.2
Stp 6	16	6.4–7.4	7.4–7.9	7.4–8.5	8.1–8.5
Stp 7	16	6.5–6.8	7.3–7.8	7.9–8.5	8.1–8.6

and cause bacterial growth (Adam & Kott 1989). It has been reported that the typically long exposure time of drinking water due to the long distance the water travels before being distributed to consumers could also affect the quality of water (LeChevallier *et al.* 1980; Gibbs *et al.* 1990). Other researchers have found that the longer the water stays in a system before being consumed, the more likely the quality is to deteriorate (Clark *et al.* 1993; Momba *et al.* 1998).

The results of this study also showed significant differences between the numbers of HPC bacteria in the polyethylene-stored water and galvanized steel-stored

Table 4 | Statistical data showing significant differences in heterotrophic plate count bacteria between polyethylene-stored water and galvanized steel-stored water

Effect	df effect	MS effect	df error	MS error	*F*	*P*
PE	6	8.50	96	0.29	29.82	0.0001
GS	1	7.21	96	0.29	25.29	0.0002
PE × GS	6	0.73	96	0.29	2.59	0.0229

df, degree of freedom; MS, mean square; *F*, F-ratio; *P*, probability.

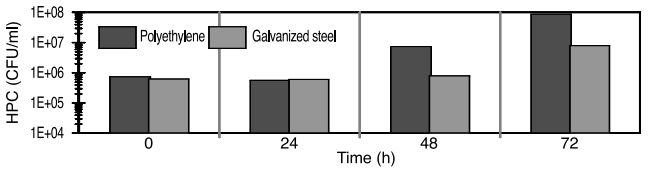

Figure 1 | Microbiological quality (HPC bacteria) of drinking groundwater collected from the reservoir.

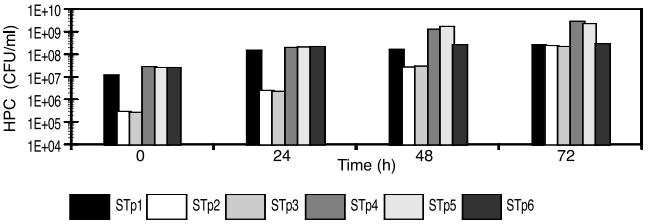

Figure 2 | Microbiological quality (HPC bacteria) of drinking groundwater collected from different standpipes and stored in polyethylene containers.

water, although an identical volume of household containers was used during the experimental study. Higher numbers of HPC bacteria were found in polyethylene-stored water than in galvanized steel-stored water for both reservoir (Figure 1) and standpipe waters (Figures 2 & 3). The Least Significant Test for HPC bacterial densities in household containers also confirmed differences between HPC in polyethylene and galvanized steel containers ($P = 0.02$; $F = 2.59$) (Table 4). It is well known that there is a relationship between the material used for the construction of drinking water distribution systems and the quality of water (LeChevallier *et al.* 1985; Roger *et al.* 1994). This principle could be also applied for the materials used during the storage of water in rural areas.

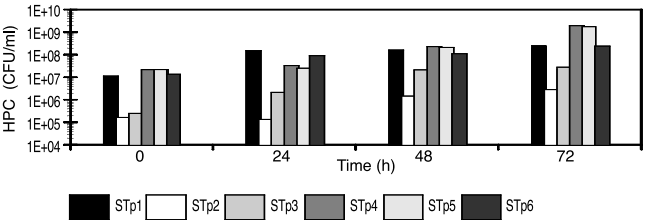

Figure 3 | Microbiological quality (HPC bacteria) of drinking groundwater collected from different standpipes and stored in galvanized steel containers.

For growth to occur, necessary elements must be available to the organism in its food supply or in the water otherwise they cannot build new cell materials. Therefore the higher number of HPC bacteria in polyethylene confirms the presence of organic compounds released by polyethylene containers during the process of water storage, although during the experimental study the level of organic compounds was not analysed.

It is also important to note that as the number of HPC bacteria increased (Figures 2 & 3) the number of faecal coliforms decreased (Table 2). Large densities of standard plate count (SPC) bacteria have been reported to interfere with the detection of coliforms (Geldreich *et al.* 1972). The authors observed that as the total bacteria population rises above 500 cfu · ml^{-1} the detection of coliforms drops to 5%, and a standard plate count greater than 500 cfu · ml^{-1} adversely affects detection of coliform organisms. Consistent with the idea of nutritional interaction is the concept of competition between HPC and coliform bacteria for limiting essential nutrients (Seligmann & Reitler 1965). Since coliforms have higher growth requirements than HPC bacteria, they are particularly susceptible to competition for nutrients in oligotrophic environments such as drinking water (LeChevallier & McFeters 1985). Therefore, it is possible that a high number of HPC suppressed the proliferation of faecal coliforms during the storage of drinking water in household containers.

CONCLUSIONS

The general bacterial content and the physico-chemical status of the intake water from the borehole were found to

be the major factors contributing to the high level of bacteria in container-stored water, although both duration of storage and the type of household containers used to store drinking water also affected the microbiological quality of water. The microbiological quality of water consistently changed with the length of storage. While the water stored for 72 h displayed a relatively lower faecal contamination level than the water stored for 24 h or 48 h, the microbiological quality of drinking groundwater consistently deteriorated when considering the level of the concentration of heterotrophic plate count bacteria in the water stored after 72 h. Although the storage period affected the quality of water, galvanized steel containers were characterized by the absence of faecal coliforms and lower levels of HPC bacteria than polyethylene containers. With respect to faecal coliform and HPC bacterial counts, it is concluded that the drinking groundwater from Mgquba village is of poor quality. Compared with the limits allowed by the *South African Water Quality Guidelines for Domestic Use,* this water is not fit for human consumption. With regard to the survival of faecal coliforms and the occurrence of HPC bacteria in the reservoir, standpipe and stored waters, others measures should be taken to improve the quality of water, namely cleaning of the groundwater distribution systems from the reservoir to the standpipes, removal of organics and sediments from the water, addition of a disinfectant or boiling of drinking water before use.

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