Changing consumer water-use patterns and their effect on microbiological water quality as a result of an engineering intervention

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Abstract

A previous study done during 1994-1995 in a section of a large, low socio-economic urban development with limited sanitary facilities and drinking-water provision indicated that the community was exposed to water-related health risks when consuming the water supplied. The study indicated that, although the public supplied water was of a good quality, the stored water, once fetched from the standpipes, deteriorated to a quality often not safe for human consumption. Based on the findings of this previous study, the local authority decided to install standpipes for each individual family in the area concerned and these were placed in the house yards. The closer proximity of the standpipes immediately altered the water-fetching and storing patterns of the community. The consequent study, on which this abstract is based, assessed the potential risk of infection posed to health by the altered water-use pattern. Weekly water samples were collected from standpipes outside as well as from containers kept inside houses of selected families. Total coliforms, faecal coliforms, heterotrophic plate counts, *Clostridium perfringens* and somatic coliphages were used as microbiological indicators. Although the improvement of water accessibility enhanced the microbiological quality of stored water, the results indicated that hygienic quality still deteriorated. This situation indicated that a suitable education and information programme to enhance the quality gains of such engineering interventions should accompany engineering improvement of water accessibility.

Introduction

The need to provide adequate water supplies to communities is a well-recognised central component of the South African Government's Reconstruction and Development Programme (African National Congress, 1994). Infection agents are regarded as the most important water quality aspect of water safety for supplied water for whatever purpose of human use (Grabow, 1996; Jagals and Lues, 1996). In developing countries, public health control over water supplied to the point of extraction by way of standpipes (pumps or taps) is often not sufficient to protect communities against water-borne infectious diseases (UNEP, 1991).

Even when a community is supplied with treated piped water, it does not necessarily mean that water-related hazards will be totally eliminated (Jagals et al., 1997). Additional aspects such as supplied water quality, domestic water storage as well as handling must be taken into consideration in any system of public water supply to ensure the consumer of safe drinking water at the point of consumption (Jagals et al., 1997).

A previous study done during 1994-1995 (Jagals et al., 1997) in a large low socio-economic urban with limited sanitary facilities and drinking-water provision, indicated that members from the involved community were exposed to microbiologically related environmental health risks when consuming water supplied by a public standpipe system.

This health risk occurred, not in the water extracted at the standpipe, but in the same volumes of water after being carried and stored at the dwellings in a variety of containers. The individual standpipes were on average 80 m away from the houses in the area, with some of the taps up to 300 m away. This implied some substantial distances over which water had to be transferred to the houses.

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The study indicated that although the supplied water at the standpipe tap was of good quality, the stored water at the dwellings deteriorated to a quality often not suitable for human consumption. The reasons for the deterioration varied from poor container hygiene and open containers subjected to environmental pollution, to the manner of handling of water by individuals in households (Jagals et al., 1997).

Based on the findings of the previous study, the local authority in the area decided to extend the system reticulation in the particular study area. A standpipe was installed for each individual family inside the boundaries of each plot of land on which a dwelling stood.

It was observed that the closer proximity of the standpipes immediately had an effect on the water-fetching and -storing profile of the members of the community. Families used more open-type buckets instead of screw-top closeable containers. The members also used more water and replenished the stored stock more often. It was also observed that the members stored less water than was previously the case.

This study was aimed at assessing the impacts of this engineering intervention on the microbiological water quality at the point of consumption. References in this study made to "before" and "after" the "engineering intervention" refers to the situation assessed during the previous (before) study of Jagals et al. (1997) while "after" refers to the situation assessed during this study.

Material and methods

Water quality parameters

The water quality parameters used to measure the environmental health risk during this study were the:

- *South Africa Water Quality Guidelines: Vol. 1; Domestic Water* (DWAF, 1996).
- Proposed *Water Quality Criteria in South Africa*, of the National Department of Health (Aucamp and Vivier, 1990).

Study area

The study was conducted in Section M, a suburb of Botshabelo in the eastern Free State. Section M is one of the lesser-developed and poorer sections of Botshabelo and possesses only limited sanitary facilities (no water-borne sewage). The community used poorly designed pit latrines (too shallow with inadequate fly proofing) and the surrounding environment for latrine. Drinking-water supply was improved from a public standpipe system in 1994 to an individual house yard standpipe system in 1996.

Scope of reporting

This report deals exclusively with the microbiological water quality aspects of the recent study. As the whole study is still ongoing and is dealing with a wider drinking water vs. health impact assessment, it was decided to report on intermediate findings that may assist decision-makers in improving accessibility to water supplies.

Sampling

Water samples were collected from standpipes outside as well as containers kept inside dwellings of families that had participated in the previous study. This was done to assess water quality changes attributed to the changes in water-use patterns by the same families due to the closer proximity of the standpipes to the dwellings.

Water samples were collected in sterile Whirlpacks® on a weekly basis. All water samples were cooled to approximately 7°C during transportation from the study area to the laboratory and analysed within 6 h of sampling.

A total of 137 water samples from the municipal supply were analysed whilst 314 water samples from the storage containers were analysed.

Microbiological analyses

Indicators

Total coliforms (TC), faecal coliforms (FC), *Clostridium perfringens* (CP), hetrotrophic plate counts (HPC) and somatic coliphages (SC) were used as microbiological indicator groups to assess possible pollution, as well as the general hygienic condition of both the supplied and stored water.

Total and faecal coliform bacteria were used as indicators for potential organic and faecal contamination in the water (*Standard Methods*, 1995). *Clostridium perfringens* was used to indicate remote faecal pollution as well as the possible presence of spore and cyst forming pathogens (Payment and Franco, 1993). Total bacterial presence in the water indicated the general hygienic quality of such water and was assessed through heterotrophic plate counts. Possible enteric virus contamination was assessed using somatic coliphages as model virus indicators (Grabow et al., 1993).

Analyses

Samples were analysed for TC, FC and CP by membrane filtering triplicate sets of 1 mℓ of sample. The 0.45 µm sterile gridded membranes were then placed on selective growth media. The plates were incubated aerobically at 35°C (TC) and 44.5°C (FC) for 24 h (*Standard Methods*, 1995) and quantified by counting typically golden-green metallic sheen colonies (for presumptive TC) and typically blue colonies (for presumptive FC).

CP plates were incubated anaerobically at 37°C for 48 h (Grabow et al., 1984) and enumerated by counting typically black colonies as presumptive CP.

Heterotrophic bacteria were enumerated from the samples by spreading 0.3 mℓ sample dilutions (dilutions were needed due to high levels of heterotrophic bacteria present in the samples) onto a non-selective medium and incubating aerobically at 37°C for 48 h (*Standard Methods,* 1995) and counting all colonies.

SC concentrations were assessed using double-layer plaque assays with *Escherichia coli* strain (ATCC 13706) as host. The plates were incubated at 37°C for 24 h (Grabow et al., 1993) and enumerated by counting all plaques.

After incubation for appropriate periods of time, colonies were counted according to the prescriptions for each group of organisms. To achieve reliable statistical quantification, the final count per 100 mℓ per sample was calculated by averaging the counts of the 3 plates/sample size/sample dilute x 100 (*Standard Methods*, 1995).

Results

Municipal supply water quality

Geometric mean levels of indicator organisms tested in supplied municipal standpipe water before and after the intervention are shown in Table 1. The preferred best estimate of central tendencies of log-normal microbiological data, such as obtained in this study, is the geometric mean (*Standard Methods*, 1995).

TC counts up to 66 organisms/100 mℓ were recorded with a geometric mean level of 6 organisms/100 mℓ in supplied municipal water (at the standpipes) before the engineering intervention, and a geometric mean value of 1 organism /100 mℓ after the intervention although a maximum count of 156 organisms/100 mℓ was recorded. In the same supply, faecal coliforms tested a geometric mean value not exceeding 1 organism per 100 mℓ with range peaks of up to 27 organisms/100 mℓ before, with a geometric mean value of zero afterwards.

Before the intervention, heterotrophic bacteria levels showed a geometric mean value in excess of 1 000 organisms /1 mℓ but after intervention this declined to a geometric mean value of 514 organisms /1 mℓ.

CP tested a geometric mean value of less than 1 organism/100 mℓ before and after the intervention. Somatic coliphages were less than one in all of the samples, before and after intervention.

Container-stored water

Geometric mean levels of indicator organisms tested in stored water supplies before and after the intervention are shown in Table 2.

Before intervention, total coliforms in household containers recorded a geometric mean value of 997 organisms/100 mℓ but declined to 25 organisms/100 mℓ after the installation of standpipes in individual yards.

Faecal coliforms tested a geometric mean value of 607 organisms/100 mℓ before and 9 organisms/100 mℓ after although the range of organisms recorded 43 000/100 mℓ. This is an indication of faecal pollution present in water.

The geometric mean value for heterotrophic bacteria tested 55 168 organism/1 mℓ before and 9 573 organisms/1 mℓ after the engineering intervention although the range of organisms recorded 572 222/1 mℓ. The increased range indicates that the general hygienic quality of the container water deteriorated.

A geometric mean value of 2 organisms/100 mℓ of CP was found in stored water before and 1 organism/100 mℓ after intervention. This is an indication of resistant faecal pollution as well as protozoa spores present in water. SCs were less than one in both the studies.

TABLE 1 GEOMETRIC MEAN LEVELS OF INDICATOR ORGANISMS TESTED IN SUPPLIED MUNICIPAL WATER AT PUBLIC STANDPIPES					
Municipal water supply	**Total coliform counts (0-5/100 mℓ)***	**Faecal coliform counts (0/10 mℓ)***	**Heterotrophic plate counts (0-100/1 mℓ)***	***Clostridium perfringens* (1/100 mℓ)****	**Somatic coliphages (0-1/100 mℓ)***
Before intervention **n = 129**	**6** (0-66)	**1** (0-27)	**3817** (0-40 000)	**<1** (0-7)	<1 <1
After intervention **n = 137**	**1** (0-156)	**0** (0-15)	**514** (0-1 137)	**<1** (0-6)	<1 <1

***** Maximum negligible risk indicator organism limits proposed by *South African Water Quality Guidelines: Vol. 1 Domestic Water* (DWAF, 1996).
** Maximum insignificant risk indicator organism limits proposed by *Water Quality Criteria in South Africa* of the National Department of Health (Aucamp and Vivier, 1990).
Geometric means of organism levels = upper line, ranges of organism levels = lower line

TABLE 2 GEOMETRIC MEAN LEVEL OF INDICATOR ORGANISMS TESTED IN CONTAINER STORED WATER					
Container supply	**Total coliform counts (0-5/100 mℓ)***	**Faecal coliform counts (0/10 mℓ)***	**Heterotrophic plate counts (0-100/1 mℓ)***	***Clostridium perfringens* (1/100 mℓ)****	**Somatic coliphages (0-1/100 mℓ)***
Before intervention n = 100	**997** (0-81 333)	**607** (0-18 333)	**55 168** (0-400 000)	**2** (0-16)	<1 <1
After intervention n = 314	**25** (0-44 900)	**9** (0-43 000)	**9 573** (0-572 222)	**1** (0-67)	<1 <1

***** Maximum negligible risk indicator organism limits proposed by *South African Water Quality Guidelines: Vol. 1 Domestic Water* (DWAF, 1996).
****** Maximum insignificant risk indicator organism limits proposed by *Water Quality Criteria in South Africa* of the National Department of Health (Aucamp and Vivier, 1990).
Geometric means of organism levels = upper line, ranges of organism levels = lower line.

Discussion

Municipal supply water

Table 1 results showed that in the previous study, as well as the present study, geometric mean total coliform levels indicated a negligible risk of microbial infection to consumers. The slightly higher TC mean in the previous study may be attributed to slight after-growth in the system - a situation that was rectified with the expansion of the system to individual plot standpipes. Although a higher maximum for TC was recorded after intervention, this could be due to sample variability especially as the mean level was lower, indicating that the rest of the counts were generally lower. This assumption is strengthened by the heterotrophic plate counts that showed after-growth in the system in the previous study but definitely a greatly reduced after-growth during the present study. Before the intervention, FC posed a higher than negligible risk of infectious disease in isolated samples - but generally these organisms were absent from the supply. The presence of faecal coliforms on average posed a negligible risk after the intervention.

Geometric mean values of CP and SC all tested one or less organism per volume unit both before and after the intervention. This indicated minimal remote faecal pollution or resistant spores and also minimal enteric viruses in the drinking water supply at the taps.

The municipal water supply quality generally posed a negligible risk in terms of the *South African Water Quality Guidelines* (DWAF, 1996) especially after the intervention.

Container-stored water

Table 2 results indicated that before and after the intervention, heterotrophic plate counts showed general contamination that may be attributed to poor hygiene inside the water containers used by consumers to store water within their dwellings. In terms of *South African Water Quality Guidelines* (DWAF, 1996), the heterotrophic plate count levels shown in Table 2, posed increased risks of infectious disease transmission.

The closer proximity of the standpipes immediately had an effect on the water-fetching and -storing profile of the community because the number of uncovered containers used increased markedly. These uncovered containers do not provide protection against environmental contaminant agents such as dust and flies.

In most cases, water is scooped with a mug placed next to the container. Such mugs were generally also exposed to unhygienic conditions such as flies, dust and unwashed hands of consumers. Although not reported in detail in this study, the mugs were swabbed for microbial contamination and were found to be of a general poor hygienic condition (Jagals et al., 1997).

Before the intervention, total coliform counts indicated an increasing risk of infectious disease transmission in terms of *South African Water Quality Guidelines* (DWAF, 1996). After the intervention, the total coliform levels decreased but were still above levels of negligible risk of microbial infection.

Before intervention, faecal coliforms indicated an increasing risk of infectious disease transmission in terms of *South African Water Quality Guidelines* (DWAF, 1996). After the intervention the levels decreased but were still well above levels of negligible risk of microbial infection.

The reason for the decreasing levels of contamination is probably the more regular replenishment of the water in the smaller containers, thereby ensuring that contaminated container water gets used before a large build-up of indicators over time can take place. However, the above results still imply that the sanitary condition of containers generally remain a risk factor even after intervention, as the frequency of water fetching together with the use of open containers increased thereby raising the potential for environmental contamination.

SC counts before and after intervention indicated a negligible risk of viral infection. This also shows no recent faecal contamination in terms of *South African Water Quality Guidelines* (DWAF, 1996).

CP counts before intervention were slightly above the insignificant risk limit proposed by *Water Quality Criteria in South Africa* of the National Dept. of Health (Aucamp and Vivier, 1990). After the intervention, CP level decreased, showing minimal remote or resistant forms of faecal contamination.

However, indications from both studies were clear that the water used from containers at home was not of the hygienic quality one would expect from a well-controlled source such as in-house running water. Methods of fetching and storing water may lead to contamination of such water as buckets storing water are often left uncovered and also not cleaned regularly even if the contents are replaced frequently. The condition of the buckets themselves may lead to a kind of contamination of otherwise good quality of water supply.

The method of obtaining water from the buckets may be the cause for the contamination of the water, because decanting mugs used are often left uncovered and are exposed to contamination by environmental inputs such as flies, dust and unwashed hands (Jagals et al., 1997).

Conclusion

The microbiological quality of water supplied to the community of Botshabelo M Section was within safe water quality limits in terms of *South African Water Quality Guidelines* (DWAF, 1996) and the proposed *Water Quality Criteria in the South Africa* of the National Dept. of Health (Aucamp and Vivier, 1990).

The engineering intervention caused water-use pattern changes that improved the overall microbiological water quality in containers stored in houses.

Although the improvement on water accessibility resulted in improved microbiological water quality in the stored water, results still indicated quality deterioration that included indications of faecal pollution probably due to environmental contamination at the point of storage and use.

A suitable education and information programme on water safety and personal hygiene should reduce the risk of microbial contamination of potable water stored in containers. Water hygiene can be seen as a very personal hygiene practice that should be promoted with each individual. This level of personal involvement in the lives of people is best achieved by involving the communities themselves. In this regard, community involvement is already seen as an essential requirement for the promotion of sanitation, health and hygiene (National Sanitation Task Team, 1996).

Participatory techniques for community involvement and education should be implemented to facilitate and drive the educational process proposed above. A typical approach that may be followed would be the Participatory Hygiene and Sanitation Transformation (PHAST) initiative of the World Health Organisation (1996) which is a participatory community capacity building initiative. This will enhance the quality gains of similar engineering interventions in future.

Additional research will be needed to investigate the actual impact of poor water quality on the actual health of the consumer that might arise from similar unhygienic container situations.

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