The health-related microbial quality of drinking water from ground tanks, standpipes and community tankers at source and point-of-use in eThekwini Municipality:

Implications of storage containers, household demographics, socio-economic issues, hygiene and sanitation practices on drinking water quality and health.

by

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Abstract

The aim of this study was to investigate the microbiological quality of drinking water at the source (taps at eThekwini laboratories, standpipes and mobile community tankers) and corresponding point-of-use (storage containers and ground tanks) supplied to peri-urban areas in Durban by eThekwini Municipality. It also aimed to identify factors associated with deterioration in water quality such as storage of water, household demographics, hygiene and sanitation practices. In order to determine the microbial quality of drinking water, the pour plate method (for enumeration of heterotrophic organisms) and the membrane filtration technique (for total coliforms and *E. coli* enumeration) were used. Conductivity, turbidity, pH and total and residual chlorine levels of drinking water were measured. Microbial and physico-chemical data was collated and statistically analysed with epidemiological data from an associated study to determine the link between microbial quality of drinking water, household demographics, health outcomes, socio-economic status, hygiene and sanitation practices. Findings showed that all point-of-use water was unsafe for human consumption as a result of either poor source water quality, in the case of standpipes, and microbial contamination at the point-of-use, in the case of ground tanks and community tankers. The latter could be attributed to unsanitary environments, poor hygiene practices or poor water-use behaviour. Households which included children aged 0-5 years and in which open-top containers were used for water storage had the highest rates of diarrhoea and vomiting. Water from ground tanks had the best microbial quality but people in households using this water presented with the highest rate of diarrhoea. Therefore provision of microbially safe drinking water will not reduce the rate of health outcomes if addressed in isolation. In order to reduce water-associated illness, provision of safe and adequate amounts of water, hygiene and sanitation education and education on water-use behaviour should be provided as a package. The provision of improved water delivery systems does not ensure that drinking water is safe for human consumption. Measures, such as point-of-use water treatment should be considered to ensure that drinking water provided at the source and point-of-use is microbially safe for human consumption.

Preface

The experimental work described in this dissertation was carried out in the School of Biological and Conservational Sciences, University of KwaZulu-Natal, Durban, from February 2005 to April 2007, under the supervision of Professor Michael Smith and Dr Nicola Rodda.

This study represents the original work by the author, Ms Urisha Singh, student number 202501371, and has not been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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I Urisha Singh declare that

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

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Abbreviations

Abbreviation	**Definition of abbreviations**	**Abbreviation**	**Definition of abbreviations**
ANOVA	Analysis of Variance	**LSD**	Lowest Significant Difference
AVG	Average	**MDG**	Millennium Development Goal
CFU	Colony forming unit	**NR**	Negligible Risk
Cl	Chlorine	**NRF**	National Research Foundation
DWAF	Department of Water Affairs and Forestry	**OCL^-**	Hypochlorite ions
E. coli	*Escherichia coli*	**PR**	Potential Risk
ECOSAN	Ecological Sanitation	**PVC**	Polyvinyl Chloride
EHEC	Enterohaemorrhagic *E. coli*	**SR**	Substantial Risk
EIEC	Enteroinvasive *E. coli*	**SD**	Standard deviation
EPEC	Enteropathogenic *E. coli*	**STEC**	Shiga toxigenic *E. coli*
ETEC	Enterotoxigenic *E. coli*	**UD**	Urine Diversion
EWS	eThekwini Water Services	**UNICEF**	United Nations Children's Foundation
GM	Geometric mean	**VIP**	Ventilated Improved Pit latrine
HCL	Hydrochloric Acid	**WASH**	Water and Sanitation Hygiene
HOCL	Hypochloric acid	**WHO**	World Health Organisation
HPC	Heterotrophic plate count		

List of SI units

List of Units

mg/L	Milligrams per litre
mS/m	Millisiemens per metre
NTU	Nephelometric Turbidity Unit
Cfu/mL	Colony Forming Unit per millilitre

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CHAPTER 1: RATIONALE OF THE STUDY

1.1 Context

South Africa is a developing country which lacks adequate supplies of potable water and sanitation for its population. The lack of infrastructure coupled with rapid population growth in certain areas is a major contributing factor to this problem. Areas with rapid population growth include the low-income rural and peri-urban settlements in South Africa. Where improved drinking water [1] has been provided to such communities, contamination of water during storage, collection and transportation is of concern since contamination would result in water that is unsafe for human consumption (Jagals *et al.* 1997; Jagals *et al.* 2004).

The World Health Organisation (WHO) and United Nations Children's Foundation (UNICEF) addressed issues pertaining to health, poverty, lack of sanitation and potable water in the Millennium Development Goals (MDGs). These goals, which serve to address the world's main development challenges, have been agreed upon by 189 nations and signed off by 147 heads of state and governments as part of the Millennium Declaration. The seventh goal, to ensure environmental sustainability, has as one of its objectives, to reduce by half the proportion of people, worldwide, without sustainable access to an improved safe water source, in urban and rural areas (UNICEF, 2007).

In order to address one of South Africa's main development challenges, government introduced the South African Free Basic Water Policy (DWAF, 2002). This policy aimed to reduce the number of South Africans without access to safe drinking water (Mosdell and Leatte, 2005). The policy states that every household is entitled to 6000 L of free water per month (25 L per person per day in a household of 8 people). Through provision of safe drinking water, government also aimed to reduce child mortality and waterborne infections. Therefore an array of South Africa's development challenges was aimed at being achieved through addressing the challenge of lack of adequate supplies of drinking water to the population (Mosdell and Leatte, 2005).

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[1] Described as water that is supplied from a protected source, *i.e.* a source that receives and supplies drinking water from a municipal drinking water treatment facility (WHO, 2005).

Having the responsibility to serve the city of Durban and its surrounding areas with drinking water, eThekwini Municipality undertook to increase the access to safe drinking water and hence address the South African Free Basic Water Policy in Durban, South Africa (eThekwini Municipality, 2005). The eThekwini Municipality covers an area of approximately 2300 km^2 and serves approximately 3.1 million people with drinking water (KwaZulu-Natal Municipalities, 2007). Low-income areas, such as rural and peri-urban areas, unlike urban areas, lack infrastructure for waterborne sewerage and high-pressure water delivery systems (in-house taps). To differentiate between areas with and without proper infrastructure for waterborne sewerage and high-pressure water delivery systems the Municipality drew a waterborne edge around the city known as the Waterborne Sewered Ring. Areas beyond the Waterborne Sewered Ring would not receive waterborne sewerage or in-house taps. Instead they are provided with Ventilated improved pit latrines (VIP)[2] or Urine Diversion (UD)[3] toilets for sanitation purposes. To address the MDG of reducing by half the proportion of people, without sustainable access to an improved safe water source, in rural and peri-urban areas in Durban, South Africa, eThekwini Municipality is supplying water to these areas via three main systems; ground tanks[4], standpipes[5] and mobile community water tankers[6] (KwaZulu-Natal Municipalities, 2007).

Water in communal standpipes and mobile community water tankers require users to collect, transport and store water prior to use whilst ground tanks themselves serve as a storage container. In the case of standpipes and mobile community water tankers, water is collected,

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[2] A form of on-site sanitation in which urine and faecal waste collect into an underground pit. This waste is broken down by bacterial interactions within the pit (WHO, 1997).

[3] A form of on-site sanitation in which, urine is kept separate from faecal waste. Faecal waste is kept dry and allowed to decompose. The decomposed material and collected urine can later be used for soil conditioning (Esrey *et al*. 1998).

[4] An on-site low-pressure water delivery system comprised of a storage tank that holds 200L of drinking water. Water is supplied via the municipal water distribution system. Tanks are placed outside households and serve individual households (eThekwini Municipality, 2005).

[5] A semi-pressure water delivery system comprised of a free standing pipe which is fitted with a tap. These structures are located outside households and serve several households, within a radius of 200m, with drinking water. It is a communal water delivery system and requires that water be collected, transported and stored in households for use. (eThekwini Municipality, 2005).

[6] A low-pressure, communal water delivery system comprising a specialized water storage vessel attached to a vehicle. The vessel is designed for transporting water from a water treatment plant to peri-urban and rural areas. Water is collected in containers, transported and stored in households till required for use.

transported to and stored in households in either open-top[7] or closed-top[8] portable storage containers. Numerous studies have demonstrated the deterioration in microbiological quality of drinking water as it moves from source[9] to point-of-use[10] (Moyo *et al.* 2004; Trevett *et al.* 2005; Gundry *et al.* 2006). Such deterioration in water quality can cause point-of-use water to be unsafe for human consumption (Jagals *et al.* 1997; Mirza *et al.* 1997; Momba and Notshe, 2003; Moyo *et al.* 2004; Trevett *et al.* 2005; Gundry *et al.* 2006). Factors contributing to deterioration in water quality include poor hygiene and sanitation practices, the use of contaminated containers to store and transport water, insertion of dirty hands into water, contact of water with particulate matter, animals and insects as a result of openings in containers, and poor environment surrounding source water (Verweij *et al.* 1991; Jagals *et al.* 1997; Hoque *et al.* 1999; Roberts *et al.* 2001; Momba and Notshe, 2003; Trevett *et al.* 2004; Trevett *et al.* 2005).

Water stored in open-top containers is more prone to faecal contamination than water stored in closed-top containers and may contain faecal pathogens that could result in illness such as diarrhoea (Hammad and Dirar, 1982; Deb *et al.* 1986; Empereur-Bissonnet *et al.* 1992; Jagals *et al.* 1997; Mirza *et al.* 1997; Roberts *et al.* 2001). Dipping utensils and hands of users may be faecally contaminated and may thus result in faecal contamination of water (Echeverria *et al.* 1987; Pinfold, 1990; Hoque *et al.* 1995; Islam *et al.* 2001; Trevett, 2003; Trevett *et al.* 2005). Water stored in closed-top containers has also been showed to become faecally contaminated as a result of techniques used to remove water from containers. Such techniques include dipping of utensils into water or direct insertion of hands into water (Swerdlow *et al.* 1992; Swerdlow *et al.* 1997).

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[7] A storage container which does not have a lid. It is therefore left open. Water that is stored in such containers is in direct contact with environmental factors and is therefore easily contaminated than water stored in containers with a cover (eThekwini Municipality, 2005).

[8] Containers which can be closed *i.e.* it has a lid. Water stored in these containers are less prone to contamination as they are more protected from environmental contaminants than water stored in open-top containers (Jagals *et al.* 1997; Trevett *et al.* 2004; eThekwini Municipality, 2005).

[9] The origin or starting point from which water supplied to a specific water delivery system or storage container originates or stems from. This is representative of water from the water treatment works (Jagals *et al.* 1997; Trevett *et al.* 2004; eThekwini Municipality, 2005).

[10] The actual point at which consumers use water from. This point is supplied with drinking water by the source (WHO, 1997).

Deterioration of point-of-use drinking water quality has also in the past been associated with the age of household members (Deb *et al.* 1986; Yeager *et al.* 1991; Qadri *et al.* 1992; Trevett *et al.* 2004). Households including children aged 5 years or younger have been shown to have higher counts of faecal pathogens and other microbes in point-of-use drinking water than households with all other age groups (Roberts *et al.* 2001). This has been shown to be especially prevalent in areas where open defaecation is practiced, since children usually have direct access to these areas. Insertion of contaminated hands or dipping utensils into water storage vessels when removing water for use can result in faecal contamination of household drinking water associated with the presence of children in a household (Hoque *et al.* 1995; Roberts *et al.* 2001; Trevett, 2003; Trevett *et al.* 2005). The presence of elderly people (greater than 50 years of age) in households has also been associated with increased microbial content of point-of-use drinking water possibly due to poor hygiene practises (Eisenberg *et al.* 2001).

Poor microbial quality of drinking water is linked to various health conditions, most typically manifesting as diarrhoea, vomiting and gastroenteritis (Chanlett, 1992; American Society for Microbiology, 2002). Diarrhoeal disease has been documented to account for 4.3% of the total global disease burden, in which 88% of cases is caused by poor quality drinking water, poor hygiene and inadequate sanitation. In South Africa, death due to diarrhoeal disease claims the fourth highest number of infant lives, only exceeded by HIV/AIDS, low birth weight and perinatal complications (Bradshaw *et al.* 2003). Thus microbial contamination of drinking water poses a risk of infection to users and needs to be controlled effectively.

The link between microbial drinking water quality and human health has been questioned. Whilst some studies, such as those by, Payment *et al.* (1991), Payment *et al.* (1993), Pinfold *et al.* (1991), Quick, (1997) and Chidavaenzi *et al.* (1998), have shown that good microbial quality of drinking water is related to a reduction in health outcomes, other studies by Esrey *et al.* (1985), Esrey *et al.* (1991) and Payment *et al.* (1993) suggest that a reduction in health outcomes is more likely to be achieved through the provision of good quality and quantity of water in conjunction with proper hygiene practices and good sanitation, rather than through the provision of microbially safe drinking water alone.

1.2 Aims of this study

The main objective of this study was to investigate the microbiological quality of stored water in eThekwini Municipality supplied by ground tanks, standpipes and community tankers. The study aimed to identify some of the factors associated with deterioration in water quality.

The specific objectives were to:

- Determine the microbial quality of drinking water from ground tanks, communal standpipes and mobile community water tankers at the source and at the corresponding point-of-use.

- Determine the implications of type of storage container used (open-top or closed-top) on the microbial quality of drinking water from communal standpipes and community water tankers.

- Determine the impact of household demographics *(viz.* age distribution of household members) on microbial quality of drinking water at the point-of-use (water stored in open-top containers, closed-top containers or ground tanks)

- Evaluate the microbiological quality of drinking water in light of water quality, sanitation and hygiene education provision.

1.3 Structure of dissertation

This dissertation comprises 6 chapters. In addition to the current chapter a review of literature in the field is presented in Chapter 2. Chapter 3 describes methodology followed by individual chapters on results (Chapter 4), discussion (Chapter 5) and conclusions and recommendations for future research (Chapter 6). References and appendices follow Chapter 6. A study on the effects of seasonality on water quality is presented in the Appendix A. This has been included as an appendix due to the use of different sampling sites for different seasons. It is acknowledged that the comparison of different communities impacts the quality of the study presented on seasonality hence this work is presented in the appendix and not in the main body of this dissertation.

1.4 Acknowledgement of data sources

This dissertation is a microbial water quality study. It included the use of data from two previous studies, with due permission of the owners of each database, as well as data collected by the author. Firstly an Honours degree study in the field of microbiology, by Swasti Maraj, completed in 2005 at the University of KwaZulu-Natal. The information used from this study is part of a database owned by the University of KwaZulu-Natal and is available to the public domain, therefore written consent for use of this database has not been included in the appendices. Secondly, a Masters of Science study in the field of epidemiology completed by Renuka Lutchminarayan in 2007. The epidemiological data used was from the Ecological Sanitation (ECOSAN) database owned by the Department of Public Health Medicine. Permission for use of this database was received from Dr Stephen Knight (Appendix B). All microbial information pertaining to Cato Manor ground tanks in this study was provided by Ms Swasti Maraj. All statistical analysis performed on these combined data sets were conducted by the author in conjunction with Ms Tonya Esterhuizen, a statistician at the School of Health Sciences, Nelson R Mandela School of Medicine and Ms Jaclyn Kelly Wright, a postgraduate student with experience in biostatistics at the Nelson R Mandela School of Medicine. All microbial and physico-chemical data for Sawpitts and Mtamuntengayo was obtained and statistically analysed by the author.

CHAPTER 2: LITERATURE REVIEW

Access to safe and reliable drinking water supplies is one of the key factors for determining health status. In 2002, diarrhoeal disease due to unpotable water and poor sanitation accounted for the second largest number of deaths in children aged 1-5 years (Mara, 2006). At that time, 1.1 billion people worldwide still required access to safe drinking water. According to more recent estimates, 25% of people lacking safe drinking water are found in sub-Saharan Africa, 40% in East Asia and 19% in South Asia (Warby, 2007).

The WHO, UNICEF and other leading organisations worldwide introduced the MDGs in an attempt to address the world's main development challenges. The MDGs have been extracted from the actions and targets of the Millennium Declaration which was approved by 189 nations and signed by 147 governments and heads of state in September 2002 at the UN Millennium Summit (UNICEF, 2007). There are 8 MDGs, each aimed at improving the quality of life of the poorest people worldwide. These goals are:

- 1: elimination of extreme poverty and hunger;
- 2: attainment of universal primary education;
- 3: encouragement of gender equality and empowerment of women;
- 4: reduction of child mortality;
- 5: improvement of maternal health;
- 6: elimination of HIV/AIDS, malaria and other diseases;
- 7: improvement of environmental sustainability; and
- 8: introduction of a Global Partnership for development.

The MDGs consist of 18 quantifiable targets that are measured by 48 indicators. These goals are required to show improvement from statistics in 1990 and are to be reached by 2015. The focus in this study is goal 7 and goal 4. The targets of goal 7 are to reduce by half the proportion of the population living without sustainable access to safe drinking water and sanitation. An indicator for this target is the proportion of people who have access to a safe water supply and sanitation facilities (UNICEF, 2007). The target of goal 4 is to reduce by two thirds the mortality rate among children less than five years of age. Diarrhoea has been demonstrated to be one of the primary causes of death in children less than five years of age.

Diarrhoea in children less than five years of age is commonly caused by poor microbial quality of drinking water, inadequate sanitation, poor hygiene, and poor water-use behaviour at the point-of-use (Deb *et al.* 1986; Empereur-Bissonet *et al.* 1992; Eisenberg *et al.* 2001; Trevett *et al.* 2005). The present study focuses on the microbial quality of drinking water being supplied to communities by a range of water delivery systems, within the eThekwini Municipal area. It also investigates the subsequent impact of water quality on health in children aged 0-5 years, children aged >5-18 years and in adults (*i.e.* household occupants >18 years of age).

South Africa is continuing to address its development challenge regarding lack of adequate water supplies through the Free Basic Water Policy which was introduced in year 2000 (DWAF, 2001). This policy was introduced to address the government's constitutional obligation to ensure provision of basic services (drinking water and sanitation) to all South Africans. Its main objective was to deal with poor service delivery levels of drinking water which contributed significantly to disease burden in poor communities (Brocklehurst, 2005). It therefore aimed to reduce the number of people without access to safe drinking water and thus reduce waterborne disease and child mortality (Mosdell and Leatte, 2005). The policy stated that every household in South Africa is entitled to 6000 L of free water per month (25 L per person per day in a household of eight people) (DWAF, 2001). Through the introduction of this policy the number of South Africans with access to safe drinking water, dwelling in rural areas, has increased from 8.6 million in 1999 to 15.7 million in 2008 (DWAF, 2008). The total population of rural dwellers in 1999 was approximately 17.9 million whilst in 2008 it was approximately 19.9 million (DWAF, 2008). Therefore, the aim to reduce by half the proportion of people without access to safe drinking water, in the context of rural areas in South Africa, has been achieved. The 2008 Millennium Development Goal progress report for South Africa shows that the proportion of urban populations with access to an improved water source[11] has exceeded the MDG target of 85.2% and currently stands at 94.8%. The proportion of rural populations with access to safe drinking water has increased from 44% in 1994 to 77.8% in 2008 and has also exceeded the MDG target of 72.2% (Lehohla, 2007; UNICEF, 2007; DWAF, 2008). Therefore the South African government has thus far been successful in implementing and receiving good service delivery results through the execution of the South African Free Basic Water Policy in South Africa.

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[11] A source that receives and supplies drinking water from a municipal drinking water treatment facility. An improved water source may also be referred to as an improved water supply (WHO, 2005).

In Durban, South Africa, eThekwini Municipality addressed the Free Basic Water Policy by providing drinking water to rural and peri-urban areas via standpipes, ground tanks and mobile community tankers. To further address this policy and the MDG number 7, eThekwini Municipality introduced a 3-pronged intervention programme. This programme ensured that every household which received a ground tank also received a UD toilet and hygiene education through the Water and Sanitation Hygiene program (WASH). During the course of this programme individuals were educated on care and use of UD toilets and ground tanks. They were also educated on the importance of good hygiene practices such as washing of hands with soap after using toilets and before cooking and eating. Water supply systems and sanitation systems used in Durban, South Africa are explained below (eThekwini Municipality, 2005).

2.1 Water supply systems in eThekwini Municipality, Durban: South Africa

Consumers provided with water by eThekwini Municipality, are supplied via mobile community water tankers (community tankers), communal standpipes (standpipes), ground tanks, semi-pressured roof tanks and high-pressure taps (eThekwini Municipality, 2005). In this study only ground tanks, communal standpipes and mobile community water tankers have been used. Brief explanations on all the water delivery systems are however included in the literature. Mobile community water tankers, communal standpipes, ground tanks, semi-pressured roof tanks and high-pressure taps are divided into three types of delivery systems: high-, semi- and low-pressure water delivery systems (Figure 1).

The high-pressure system consists of high pressure taps and communal standpipes (Figure 1). Unlike communal standpipes, high-pressure taps is least susceptible to external contamination as water is not stored or transported outside the distribution system and hence introduction of external contaminants is minimised. Semi-pressure systems including roof tanks are more susceptible to external contamination than high-pressure systems since water from these sources are usually stored, transported or exposed to environmental factors that impact on microbial water quality. Low-pressure systems are comprised of mobile community water tankers and ground tanks (Figure 1). Low-pressure systems are generally most prone to microbial contamination due the storage periods of water either in storage containers or within ground tanks themselves (eThekwini Municipality, 2005).

Water from the treatment plant is distributed to mobile community tankers, communal standpipes and on-site ground tanks (Figure 1). Mobile community tankers and communal standpipes are sources of drinking water and the corresponding point-of-use for these delivery systems is household storage containers which may be either open-top or closed-top. With regard to the ground tank delivery system, the on-site ground tank is the point-of-use as it is found in the yard of individual households and hence does not require collection of drinking water. The source for this delivery system would be any point in the municipal distribution system (explained further in Figure 2, Chapter 3).

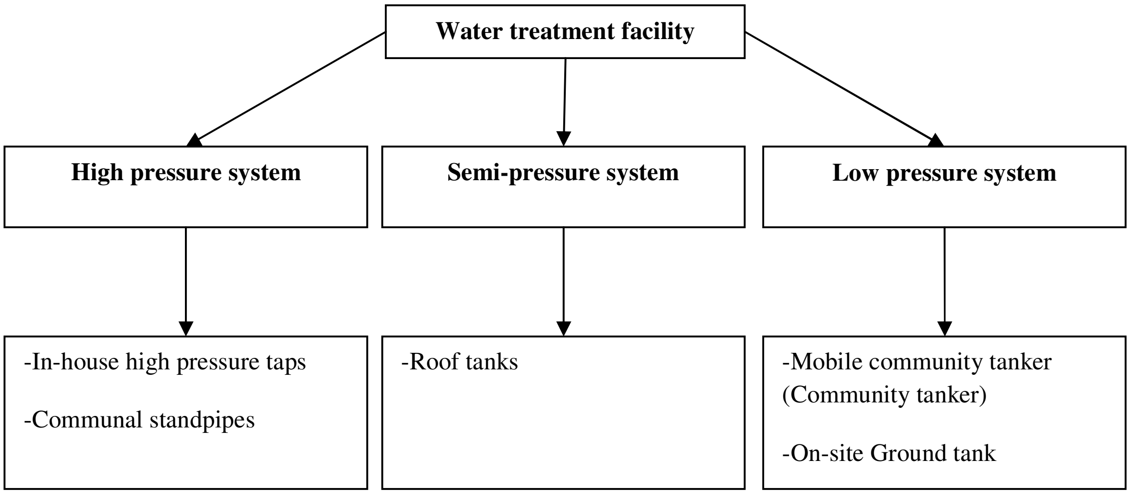


Figure 1 Schematic diagram representing the three types of water delivery systems which receive water from treatment facilities. The water delivery systems include the high-pressure, semi-pressure and low-pressure water delivery systems.

2.1.1 High-pressure taps

These water delivery systems are found in fully developed areas, where a functioning piped distribution system and waterborne sanitation exist. (Durban Metro Water, 2002; eThekwini Municipality, 2005). Contamination of water in this system is not as widespread as that of the low-pressure delivery systems as water is delivered directly from the water treatment plant via pipelines to taps in the house. No storage of water is involved, therefore chances of contamination through transportation and storage of water is minimised. This system was not included in the focus of this study, so will not be considered further.

2.1.2 Roof tank water delivery system

Roof tanks can supply in excess of the 200 L of free basic water per day, *i.e.* after supplying 6000 L (200 L x 30 days = 6000 L) of free basic water for the month all other water used is billed for. It works on a meter basis whereby, once the 6000 L of free water is drawn, all further water used is billed for. Tanks are continually filled with water, which they receive from a water treatment plant via pipelines. (Durban Metro Water, 2002, eThekwini Municipality, 2005). This system is not included in the focus of this study, so will not be considered further.

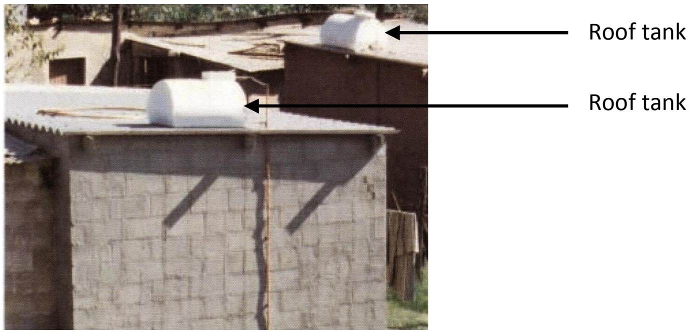


Figure 2 Illustration of a water storage tank (roof tank) located on the roof of a household.

2.1.3 Communal Standpipes (Standpipes)

Standpipes are a communal high-pressure water delivery system which is typically used in informal and peri-urban settlements (DWAF, 1994). A single standpipe can serve several hundred people with water on a daily basis. The Department of Water Affairs and Forestry Water Supply and Sanitation Policy (1994) states that standpipes should be located no further than 200 m from a household, although it is recognized that there are still areas where this is far from being achieved (DWAF, 1994; Jagals *et al.* 1997). Water is collected from standpipes in containers and transported to households, where it is stored and used. Water from standpipes is drawn from a distribution pipe with a tap (Figure 3). This water is prone to contamination because of collection, transport and storage methods used at the household level (Jagals *et al.* 1997). Storage and collection containers are often contaminated with microorganisms which adhere to the container surfaces. In this way bacteria can enter water used for drinking purposes, amongst others, and can represent a health hazard. The organic compounds in water and material used to manufacture storage and collection containers, such as polyethylene, may serve as a source of nutrients for bacterial growth and proliferation, thereby contaminating water and placing consumers at risk (Momba and Mnquemvu, 2000; Momba and Kaleni, 2002; Momba and Notshe, 2003).

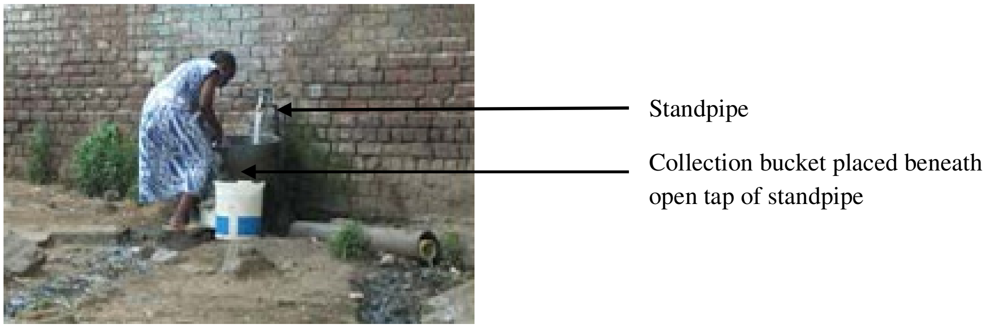


Figure 3 A resident filling a bucket with water from a communal standpipe.

2.1.4 Ground tanks

Ground tanks are located in the yard of households. Houses supplied with ground tanks are equipped with on-site sanitation services such as VIP or UD toilets. Ground tanks are only used in areas where the plot size is large enough to accommodate a hydraulic load of 200 L per day. It is found mainly in rural and peri-urban areas. Ground tanks are made of polyvinyl chloride (PVC) and can hold up to 200 L of water. They are re-filled with treated water every evening through a piping system from the treatment works operated via an electronic switch mechanism. A tap is present at the bottom of each tank and serves to release water from the tank when required (Figure 4) (Durban Metro Water, 2002; eThekwini Municipality, 2005). Water in ground tanks is prone to contamination since tanks are used as the container in which water is stored in for 24 hours. Water and the container surface can provide nutrients for growth and proliferation of bacteria, which may either be found floating in water (planktonic bacteria) or attached to the inner surface of containers (biofilm) (Lehtola *et al.* 2004). Bacteria from biofilm may be released into water when shear forces are applied to biofilm layers, such as when the tank is refilled (LeChevallier *et al.* 1980; LeChevallier *et al.* 1991; Block *et al.* 1993). This bacterially contaminated water may then be used by the consumer for drinking purposes and could represent a potential health hazard if bacteria are pathogenic. Since the recent increase in free basic water provision to 300 L per day, ground tanks will gradually be phased out and replaced with electronic bailiffs (devices attached to distribution pipes to limit water supply to free basic water provision). It may be expected that this will decrease opportunities for contamination. The use of UD toilets in combination with ground tanks, as implemented by eThekwini Municipality to some peri-urban areas in Durban, has been shown to reduce incidences of diarrhoea, vomiting and worm infestations in a study by Lutchminarayan in 2007. This is thought to be largely due to the better hygiene practices associated with the use of this sanitation system as a result of the provision of sanitation, water and hygiene education provision as a package.


200 L Ground tank placed on an elevated surface

Pipe through which ground tank is refilled with treated water

Tap on ground tank through which water is released

Buckets in the vicinity of ground tanks.

Figure 4 Ground tanks located in the yard of a house. A pipe allows for the tank to be re-filled with water from the municipal distribution system every 24 hours. A tap at the lower end of the tank allows for water to be released from the tank as required.

2.1.5 Mobile Community water tankers (Community tankers)

A mobile community water tanker (hereafter referred to as community tanker) is a low-pressure communal water delivery system which consists of a large tanker attached to a vehicle (Figure 5) (eThekwini Municipality, 2005).

This tanker is filled with treated water from the water treatment works. It transports water to target areas, typically those not yet supplied with standpipes or ground tanks. Community members then collect water directly from the tanker via a tap on the tanker. Water is then transported to and stored in households for use (eThekwini Municipality, 2005).

Water from community tankers is also susceptible to contamination during collection, transportation or storage, or as a result of poor hygiene within the tanker since the interior is difficult to access and hence clean (eThekwini Municipality, 2005).

Mobile community tanker filled with drinking water from a collection point at the municipal treatment plant.

Pipe system through which the tanker is emptied and refilled.

Figure 5 Illustration of a mobile community tanker. Tankers are filled with treated water at the treatment plant. Thereafter it is transported to target areas were community members collect water from tankers via a tap. This water is then transported to and stored in households for use.

2.2 Sanitation systems in eThekwini Municipality, Durban: South Africa

Ventilation improved pit latrine systems and UD toilets are the two major types of sanitation used by rural and peri-urban dwellers in Durban. The UD toilets were introduced at the same time as ground tanks for water supply. eThekwini Municipality provided ground tanks and UD toilets as a package in order to promote good sanitation practices and hence maintain the microbial and sanitary quality of drinking water. Pit latrines are being replaced by UD toilets due to the contamination of ground water and accessibility problems for emptying VIP toilets (eThekwini Municipality, 2005)

2.2.1 Ventilation improved pit latrines (VIP)

In pit latrines, there is presently a mix of older pit latrines of various constructions and of VIP latrines since being implemented in 1994. Faeces and urine collects into a common reinforced pit (Figure 6). The waste material in this pit is broken down by natural bacterial reactions. The additional features of a VIP latrine includes a ventilation pipe which extracts air from the toilet when wind blows in order to prevent odour, it also includes an enclosed pit (Buckley *et al*. 2008). The problem with these toilets however, is that the wet system results in odour which is not controlled solely by the ventilation pipe. This attracts flies to the area and is a health concern (WHO, 1997). It is due to such issues with this system that the UD toilet system was developed and implemented (Winblad, 1996).

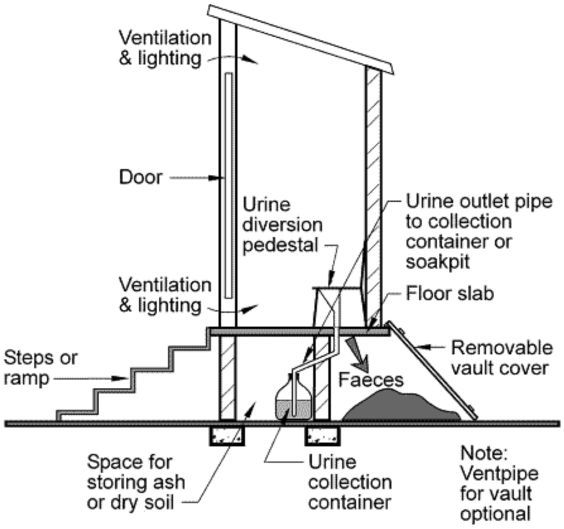
*(Source: www.cemforce.co.za)

Figure 6 Illustration of a ventilated improved pit latrine.

2.2.2 Urine diversion toilets (UD toilets)

Urine diversion toilets make use of technology in which urine is separated from faecal waste so as to keep faecal waste dry (Esrey *et al*. 1998). This is facilitated by a special design of the toilet (Figure. 7) in which urine is diverted via a pipe / tube into a collection container or soak away and faecal waste is collected into a vault immediately beneath the toilet (Esrey *et al*. 1998). These toilets may have a single vault or a double vault. In Durban UD toilets are double vaulted. This allows for the decomposition of the contents of the first vault whilst the second vault is being used, and *vice versa*. After defaecation sand is spread over faeces to absorb moisture and control odour. It is important to keep faecal waste dry to promote dessication of faecal material and to control odour and flies. The dehydration of faecal waste helps in the destruction of harmful bacteria and viruses over time (Esrey *et al*. 1998). This dehydrated, decomposed faecal material can then be used for soil conditioning, although eThekwini Municipality instructs users to bury the vault contents on site. Included in the design of the UD toilet structure is also a sink, which can be used for washing of hands thus promoting hygiene practices in an attempt to reduce incidences of diarrhoea and vomiting caused by ingestion of faecal bacteria through the oral-faecal route. Found on the door of each UD toilet in Durban is a flyer with instructions on the proper use of UD toilets and associated hygiene practices, thus encouraging and educating users on proper handling and use of UD toilets (eThekwini Municipality, 2005; Lutchminarayan, 2007).

There are several advantages linked to the use of UD toilets in comparison to the use of VIP latrines. Firstly, UD toilets, if used correctly, have fewer odours and flies than VIP toilets and are thus conducive to installation within homes. Secondly the vault can be constructed above ground and hence will not affect soil quality or pollute groundwater. Thirdly, the faecal compost and urine generated from these toilets may be used in rural and urban agriculture. Fourthly, no water is required to use this system and lastly, no expensive treatment of sewage is required (Morgan, 1999; SUDEA, 2000).



*(Source: www.cemforce.co.za)

Figure 7 Illustration of the structure of a urine diversion toilet.

2.3 Contamination of drinking water

The problem with water supplied by standpipes and community tankers however, lies in potential contamination of water during collection, storage and transportation, since these delivery systems are communal. For users who do not have continuous in-house private water services, these users are at risk of consuming microbially contaminated water because of contamination during transport and storage of drinking water (Momba and Notshe, 2003; Moyo *et al*. 2004; Trevett *et al*. 2005; Gundry *et al*. 2006). Inconsistency in hygiene and proper sanitation practices is a major contributing factor to such contamination (Echeverria *et al*. 1987; Pinfold, 1990; Swerdlow *et al*. 1992; Hoque *et al*. 1995; Tuttle *et al*. 1995; Roberts *et al*. 2001; Trevett *et al*. 2004).

Collection and storage of large quantities of water over a long period of time occur with accompanying potential for deterioration in water quality (Bailey and Archer, 2004; Genthe *et al.* 1997; Gundry *et al.* 2004; Jagals *et al.* 1997; Jagals *et al.* 1999; Jagals *et al.* 2004; Wright *et al.* 2004). Studies conducted in the Ncera and Ntselamanzi rural villages in Harare, Zimbabwe, demonstrated that water supplied to communities via standpipes was contaminated by large numbers of pathogenic microorganisms (Momba and Kaleni, 2002). Contamination was attributed to collection, transportation, storage and water-use practices (Momba and Kaleni, 2002). In rural and peri-urban areas a single standpipe may serve hundreds of households. The location of standpipes may be viewed as being remote to certain users. Regulations state that standpipes should not be more than 200 m away from households using the water supply, but in some instances people travel up to 750 m for water (Momba and Kaleni, 2002).

Drinking water from communal delivery systems, such as standpipes and community tankers, is collected and stored in either open-top containers or closed-top containers. The type of storage container and the handling thereof impacts on the microbial quality of point-of-use drinking water (Shiffman *et al.* 1978; Jagals *et al.* 1997; Hoque *et al.* 1999; Trevett *et al.* 2004*).* Studies have shown that contributors to drinking water contamination include insects, and airborne and particulate matter that enters drinking water through openings in containers. Contaminated cloths used to wipe storage containers or taps during the collection and transfer of water, introduction of dirty hands into water, poor hygiene and sanitation practices and presence of animals also contribute to microbial contamination of collected drinking water (Feachem *et al.* 1978; Shiffman *et al.* 1978; Khairy *et al.* 1982; Heinanen *et al.* 1988; Verweij *et al.* 1991; Hoque *et al.* 1999; Roberts *et al.* 2001; Momba and Notshe, 2003; Trevett *et al.* 2005).

Utensils used to remove water from storage containers can also cause contamination of drinking water. Bacteria or particulate matter adhering to utensils can enter drinking water (Jagals *et al.* 1997). Storage vessels also offer a route for contamination as their inner surfaces may have microbes attached to it as a result of biofilm[12] development or poor hygiene of containers (Donlan and Pipes, 1988; LeChevallier *et al.* 1991; Tokajian *et al.* 2000; Arjun *et al.* 2004). Water in ground tanks is also susceptible to contamination through the formation of biofilm. Biofilm microorganisms utilise carbon and other organic nutrients

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[12] A biofilm can be described as a structured community of microorganisms which are encapsulated in an extracellular polymeric matrix which they produce. Biofilms are found attached to surfaces that are in contact with water (Xavier *et al.* 2005).

from water and container surfaces for growth and proliferation, hence contamination of water occurs (LeChevallier *et al*. 1990; Mittleman, 1995). Insufficient hygiene education of water users is a major contributing factor for poor water quality since storage and collection containers are seldom washed and hence microorganism growth is not hindered (Swerdlow *et al*. 1992; Hoque *et al*. 1995., Swerdlow *et al*. 1997; Jagals *et al*. 1999; Medical Research Council, 1999; Coulson, 2000; Nala *et al*. 2003; Trevett and Carter, 2008).

The deterioration of water quality between the source and point-of-use is thus a serious concern (Clasen and Barstable, 2003; Trevett *et al*. 2004; Wright *et al*. 2004; Maraj *et al*. 2005; Trevett *et al*. 2005). Such microbial deterioration can result in increased incidence of adverse health outcomes such as diarrhoea and vomiting in children less than five years of age (Yeager *et al*. 1991; Qadri *et al*. 1992; Mirza *et al*. 1997; Mahmud *et al*. 2001).

The microbial quality of drinking water is established by testing for certain microorganisms in drinking water samples. These organisms are known as indicator organisms and they assist in determining the quality of drinking water eThekwini Municipality, 2005).

2.4 Water quality with microorganisms as indicators

Indicator microorganisms are used to evaluate the microbial quality of drinking water and its safety for human consumption. Safe drinking water can be defined as drinking water which is devoid of harmful chemicals or microorganisms that can cause illness in humans if present in certain concentrations (McFeters, 1990; Prescott *et al*. 1993; WHO, 2001). Due to the large number of microbes that can contaminate drinking water, it is impossible to analyse for every type of microbe. Therefore, a few microorganisms have been selected as indicators of water quality (WHO, 1993; DWAF, 1996; Water Research Commission, 1998; WHO, 2001). According to the South African Water Quality Guidelines (DWAF, 1996), for an organism to be classified as an indicator it needs to satisfy the following requirements:

- It has to be suitable for all water types.
- It must be present in polluted waters including sewage.
- It must be absent in unpolluted water.
- It must be present in numbers that correlate with the degree of pollution.
- It must be present in higher numbers than the pathogen.

- The survival of the organism in water must at least be as long as the pathogen's survival time.
- It must not be pathogenic or unsafe to work with in a laboratory and
- It must be detectable by practical and reliable methods (DWAF, 1996).

The most common indicators used in the analysis of drinking water quality include heterotrophic organisms, total coliforms, *E. coli* and somatic coliphages. The presence of indicator organisms in drinking water could be indicative of poor sanitary or general quality of water or it could indicate inefficiency in treatment processes (WHO, 2005). Indicator organisms used in this study included heterotrophic organisms, total coliforms and *E. coli*.

2.4.1 Heterotrophic organisms

Heterotrophic organisms consist of ubiquitously present microbial flora including *Acinetobacter*, *Aeromonas*, *Flavobacterium*, *Klebsiella*, *Moraxella*, *Serratia*, *Pseudomonas* and *Xanthomonas* species (Davies and McFeters, 1988). Heterotrophic organisms can proliferate rapidly and successfully in water or in biofilm. They are used as an indicator of general water quality in terms of increased general organic load. Following water treatment, the number of heterotrophic organisms should be low (between 0 and100 colony forming units per millilitre (cfu/mL) (DWAF, 2005; WHO, 2005). If heterotrophic organism counts are high after treatment (>100 cfu/mL) the inference is that treatment processes are inefficient (DWAF, 1996; DWAF, 2005). If heterotrophic organism counts are high in water from distribution systems or stored water, the implication is that regrowth has occurred in the distribution system or that biofilm is present in either the distribution system or the storage containers. Environmental contamination of water could also have occurred. This leads to questioning of general water quality and to testing for more specific indicators (DWAF, 1994; DWAF, 1996; WHO, 2005) (Table 1).

2.4.2 Total coliforms

Total coliforms is a group of bacteria that are found in the environment, natural waters and in the faeces of all warm-blooded animals including humans. These bacteria are able to survive and grow in water and are hence used as indicators of water quality (Rompre *et al*. 2002). The presence of total coliforms in drinking water is indicative of treatment efficacy, regrowth and general hygiene status of water in distribution systems. The presence of total coliforms is also used as an indicator of the potential presence of disease-causing microbes (pathogens) in drinking water. Following water treatment procedures, total coliforms should be absent in drinking water. Their presence points toward treatment inefficiency if found after treatment. If detected in stored water and distribution systems, biofilm presence, regrowth in distribution systems or contamination of water with faecal waste, soil or plant debris are suspected (DWAF, 1996; Momba and Kaleni, 2002; WHO, 2005).

2.4.3 *Escherichia coli (E. coli)*

E. coli is a species of bacteria found in human and animal faecal matter (Feng *et al*. 2002). Their presence in drinking water is indicative of faecal pollution of water and the potential presence of faecal pathogens. Presence could also indicate inefficient water treatment since water treatment processes (*e.g.* chlorination) are intended to remove faecally-derived bacterial pathogens. *E. coli* is sensitive to disinfection processes using chlorine (Edberg *et al*. 2000; WHO, 2005; Allen *et al*. 2008).

The WHO guidelines for drinking water state that for water to be safe for human consumption, heterotrophic organism counts must be between 0 and 100 cfu/mL whilst *E. coli* must be absent and total coliforms should be between 0 and 5 cfu/100mL (WHO, 1993 and WHO, 2005). According to South African Water Quality Guidelines, for drinking water to be safe for human consumption, heterotrophic bacteria must be present in counts lower than 100 cfu/ml, total coliforms must not exceed 5 cfu/100ml and *E. coli* should be absent from water (Table 1).

The table derived from the South African Water Quality Guidelines, given below, also indicates the level of risk of microbial infection posed to users of drinking water based on the specific counts of indicator microorganisms as per South African Water Quality Guidelines (DWAF,1996).

Table 1 Summary of South African target water Quality Guidelines for domestic water quality, acceptable counts of heterotrophic organisms, total coliforms and *E. coli* in drinking water.

Heterotrophic organisms (HPC cfu/mL)	**Total coliforms (cfu/mL**	***E. coli* (cfu/100mL)**	**Description**
0-100	0-5	0	Negligible risk (NR) of microbial infection
100-1000	5-100	0-10	Potential risk (PR) of microbial infection. Indication of inadequate water treatment and possible post-treatment contamination and/or regrowth in the water system
>1000	>100	>20	Substantial risk (SR) of microbial infection. Indication of inadequate water treatment and possible post-treatment contamination and/or regrowth in the water system.

*Table derived from DWAF, 1996.

2.5 Water Quality - physico-chemical parameters

The physico-chemical parameters of drinking water, including the pH, temperature, total and residual chlorine levels, turbidity and conductivity, are important indicators of water quality. They can also influence the microbial quality of drinking water at the source and corresponding point-of-use (Momba and Kaleni, 2002; Momba and Notshe, 2003). Physico-chemical parameters used to determine the quality of drinking water are explained below.

2.5.1 pH

The pH of a substance can be described as the acidity or basicity of a solution (Norby, 2000). The pH of water has an effect on microorganism growth and also affects biofilm development. Guffanti *et al.* (1984) and Mayo and Noike (1994) showed that pH of water influences ion transport and biomass regulation in microorganisms. A pH closer to neutrality favours microorganism proliferation to a greater extent than a more basic pH. A pH closer to neutrality results in an increase in the metabolism of microorganisms and hence an increase in microbial growth and proliferation.

2.5.2 Temperature

One of the most important factors influencing bacterial growth in drinking water is temperature (LeChevallier *et al.* 1980; Donlan and Pipes, 1988; Donlan *et al.* 1994; LeChevallier *et al*. 1996; Momba and Notshe, 2003). The higher the temperature, the faster the regrowth of microorganisms (Tokajian *et al.* 2000). Microorganisms are incapable of regulating their own internal temperature and are dependent on ambient temperature and pH to influence their biomass composition, nutrient requirements, nature of metabolism and their rate of metabolic reactions (Pirt, 1971; Novak, 1974; Esener *et al.* 1981). An increase in temperature causes pH of water to approach neutrality and hence favours microorganism growth. Without the correct temperature, the rate at which organisms utilise substrates could be compromised and hence their growth and metabolism reduced. Microorganism growth is increased when temperatures reach 15°C or more (LeChevallier *et al.* 1996; Power and Naggy, 1999). Lund and Ormerod (1995) have also shown that biofilm formation in different drinking water systems are closely influenced by temperatures above 5°C. High temperatures also cause a reduction in residual chlorine and total chlorine levels, since chlorine volatilizes as Cl_2 gas more readily at higher temperatures. Therefore microorganism growth increases since the high temperature increases the metabolism of the organism and the low residual chlorine levels are not enough to destroy microbes (LeChevallier *et al.* 1980; Donlan and Pipes, 1988; LeChevallier *et al*. 1996; Donlan *et al*. 1994; Momba and Notshe, 2003).

2.5.3 Turbidity

Turbidity can be described as a measure of the amount of light that is scattered and absorbed by water as a result of suspended matter found in the water. It is used to quantify the amount of suspended solids in water (Allen *et al*. 2008). Turbidity in drinking water can be caused by suspended or colloidal matter including, silt, soil, clay, organic and inorganic matter and microorganisms (APHA, 2005). In drinking water systems where chemical disinfection (such as chlorine disinfection) is used, the type of turbidity rather than the amount of turbidity is more important. This is because organic matter, a source of turbidity, in drinking water can react with chemical disinfectants resulting in the production of disinfectant by-products which could potentially have long-term health effects on humans (Edberg *et al*. 2000). Turbid water is often brown and may have unpleasing aesthetic qualities (appearance, odour, taste). According to drinking water guidelines by DWAF (1996, 2005) and WHO (2005) the turbidity of drinking water should be below one Nephelometric Turbidity Unit (NTU) and must not exceed five NTU (Table 2). Above five NTU a discoloration in drinking water is noticeable. Higher values imply that water may be unsafe for human consumption. High values could be attributed to rusting pipes or storage vessels, or to inefficient treatment procedures. (Muyima and Ngcakani, 1997). Turbid water could favour microbial growth since suspended particles provide surfaces for attachment of microorganisms and higher nutrient content to support microbial proliferation and biofilm development (McCoy and Olsen, 1986; Miettinen *et al*. 1997; Sathasivan *et al*. 1997; Percival *et al*. 2000; Lehtola *et al*. 2004; Allen *et al*. 2008).

2.5.4 Free and residual chlorine

Chlorine is the most commonly used disinfectant, the purpose of which is to eliminate microbes from drinking water and prevent regrowth of microorganisms in drinking water systems and storage vessels (Gorchev, 1996). If chlorine levels are too low, proliferation of microorganisms will occur. According to WHO guidelines, each litre of drinking water should be treated with 2.5 mg of chlorine as the last stage of treatment (WHO, 2005). If temperatures are above 18°C, water should be allowed at least 30 minutes to react with chlorine. If temperatures are lower, a shorter reaction time is acceptable. Only 2 mg/L of chlorine is required to remove most bacterial contaminants from drinking water, the remaining 0.5 mg/L serving as residual chlorine (free chlorine) (WHO, 2005). The purpose of residual chlorine is to eradicate any contaminants that may enter drinking water during storage or transportation and to prevent regrowth of microbes in the distribution system and storage vessel. Therefore if chlorine levels are below the recommended levels at the source or point-of-use, microbial regrowth may not be controlled. The pH and turbidity of water affects the efficacy of chlorine (Gorchev, 1996). When chlorine is added to water it hydrolyses and yields hypochloric acid ($HOCl$) and hydrochloric acid (HCl). The hydrolysis to produce hypochloric acid is completed at a pH that is greater than 4. Since hypochloric acid is a weak acid, it partially dissociates into hypochlorite ions (OCl^-). In comparison to hypochlorite ions, hypochloric acid is a more efficient disinfectant and therefore a pH which favours a higher ratio of hypochloric acid to hypochlorite ions favours better disinfection of drinking water. At pH 6.5, approximately 90% of free chlorine is present as hypochloric acid whilst at a pH 9 the hypochlorite ions are more dominant. Therefore better disinfection occurs at a lower pH (Morris, 1982). Turbidity affects the disinfection efficacy of chlorine by providing a form of protection for microorganisms from chlorine. By doing so, an increase in oxygen and chlorine demand is created (WHO, 1996). The ideal conditions recommended by WHO for efficient chlorination is a pH of less than eight, turbidity between one and five NTU, a residual chlorine level of no less than 0.5 mg/L and a contact time of water with chlorine for at least 30 minutes (WHO, 1993; WHO, 1996)

2.5.5 Conductivity

Conductivity is measured as the electrical current which can be conducted by a water sample. Charged ions in water allow for the creation of an electric current. Conductivity increases as the concentration of ions increases. Hence conductivity is used as a measure of dissolved ions in water. Water with a high conductivity generally has a higher dissolved material content than water of low conductivity. The dissolved material could include contaminants or nutrients and therefore high conductivity values in drinking water are of concern since either microbes or substances that support microbial growth or microbial attachment could be present. Also, high conductivity could indicate the presence of salts or other ions which could cause encrustation or corrosion of distribution systems (WHO, 1979; Henley, 1995). According to WHO and DWAF (South Africa) guidelines for drinking water to be considered safe for human consumption, the physico-chemical parameters set out in Table 2 must be met. The failure of drinking water to meet these criteria implies that water may be unsafe for human consumption and hence can possibly cause adverse effects, particularly microbial infection.

Table 2 Guidelines for recommended physico-chemical parameters in drinking water.

Physico-chemical parameter	WHO guidelines 2005	DWAF guidelines 1996
Total Chlorine	2.5 mg/l	2 mg/l
Residual chlorine	0.2-0.5 mg/l	0.2-1.5 mg/l
Temperature	25°C	25°C
pH	7 - 8.2	5 – 9.4
Turbidity	Less than 1 NTU and not greater than 5 NTU	Less than 1 NTU and not greater than 5 NTU
Conductivity	< 100 mS/m	< 100 mS/m

*Table modified from: DWAF, 1996, DWAF, 2005, WHO, 1993 and WHO, 2005.

Microbial contamination of drinking water coupled with poor physico-chemical properties of water may result in the presence of microbes or pathogenic organisms in drinking water which could cause illness in humans. Vectors of water-associated diseases and health outcomes associated with the presence of such vectors are discussed below.

2.6 Waterborne diseases and health outcomes considered in this study

Water-related disease is a problem experienced worldwide. It is caused by contamination of water by animal, human or chemical wastes (WHO, 1993; WHO, 2005). There are four types of water-associated diseases: waterborne, water-washed, water-based and water-related diseases (Bradley, 1977). Waterborne diseases are caused by consuming food or drinking water contaminated with pollutants. The most common waterborne diseases include gastroenteritis, diarrhoea, typhoid fever, cholera, hepatitis and shigellosis. Pathogenic protozoa such as *Giardia lamblia* and *Cryptosporidium parvum* can also contaminate drinking water and cause diseases such as cryptosporidiosis and giardiasis, which can be lethal in severe cases (Bradley, 1977; Ford, 1999; Payment and Hunter, 2001). Among helminthic parasites, *Ascaris lumbricoides* is an intestinal parasite that infects approximately 25% of the world's population annually (Crompton, 1988). Water-washed diseases occur as a result of poor personal hygiene and skin contact with contaminated water. Examples are ascariasis, scabies and skin sores (Bradley, 1977; WHO, 1993). Water-based diseases are caused by parasites that are found in organisms such as bilharzias living in water. Water-related diseases occur as a result of insect vectors that breed in water. Malaria is an example of this type of disease which is transmitted by a mosquito vector (WHO, 1993; Bradley, 1977; Peterson *et al.* 1998).

The current study uses occurrences of diarrhoea and vomiting to illustrate a link, if present, between microbial quality of drinking water, hygiene, sanitation, socio-economic status, poverty index and health. Diarrhoea and vomiting are symptoms of several water-associated diseases, including those caused by vectors as described below.

2.6.1 Vectors of water-associated disease

Diarrhoea is not in itself a disease; it is rather a syndrome/symptom of several diseases. Diarrhoea can occur as a result of gastroenteritis which is commonly caused by viruses, bacteria or protozoa (Wilson, 2005). Examples of diarrhoeal diseases[13] include; cholera, typhoid, bacillary dysentery (shigellosis), giardiasis and cryptosporidiosis (Water Aid, 2008). Diarrhoea is also a manifestation of enteric viruses such as norovirus. Diarrhoea can be defined as the release of three or more loose or watery stools in a 24 hour period (Baqui *et al*., 1991). Individuals with diarrhoea suffer rapid depletion of water, sodium and ions from their bodies. If more than 10% of the body fluid is lost per day the individual dies (Water Aid, 2008). If diarrhoea persists for more than 3 days dehydration may occur, thus resulting in severe health impacts and even death in extreme cases (Baqui *et al.* 1991; Water Aid, 2008). Several studies have used the incidence of diarrhoea as an indicator of poor hygiene practices and environmental conditions including poor water quality and sanitation.

2.6.1.1 *E. coli*

There are several different strains of *E. coli* that cause diarrhoea. The principle subgroups are Enteropathogenic *E. coli* (EPEC), Enteroinvasive *E. coli* (EIEC), Enterotoxigenic *E. coli.* (ETEC), Enterohaemorrhagic *E. coli* (EHEC) and Shiga toxigenic *E. coli* (STEC) (Centre for Disease Control, 2008a). The EPEC subgroup is a common cause of diarrhoea in children whilst EIEC causes illness similar to shigellosis in humans. The ETEC subgroup causes travellers' disease, in which bacteria enter the cells of the small intestine and release enterotoxin. This results in abdominal cramps, vomiting and diarrhoea. The STEC subgroup of *E. coli* produces shiga toxins whilst the EHEC strain is associated with enterohaemorrhagic colitis in humans. Both these subgroups have associated virulence factors. *E. coli* O157 is the most common serotype of *E. coli* that is associated with EHEC. It is also the most dangerous and causes severe diarrhoea. In some cases it causes haemolytic uraemic syndrome and death (American Society for Microbiology, 2002; Centre for Disease Control, 2008d). Haemolytic uraemic syndrome is a disease which results in acute renal failure as a result of an inflammatory response that occurs upon exposure of the renal endothelium to shiga toxin. Disseminated intravascular coagulation occurs and the fibrin mesh that is formed captures thrombocytes and destroys red blood cells leading to a reduction in both counts. Its peak incidence is in children between 4 months to six years of age (Corrigan and Boineau, 2001).

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[13] Diarrhoeal disease refers to a disease in which diarrhoea is a symptom or manifestation (Wilson, 2005).

2.6.1.2 *Vibrio cholerae*

Vibrio cholerae is the causative agent of cholera. Cholera can be described as an acute diarrhoeal illness which occurs upon consumption of drinking water or food contaminated with faecal waste containing cholera-causing bacteria, *Vibrio cholerae* (Centre for Disease Control, 2008b). Symptoms occur after ingestion of the bacterium contained in contaminated water or food. The bacterium enters the small intestine and produces a toxin which is a potent stimulator of adenylate cyclase. This causes secretion of watery fluids, rich in sodium, potassium and bicarbonate from the intestine. In severe cases the rate of loss of these nutrients exceeds the absorptive capacity of the intestine. Cholera presents with vomiting, abdominal cramps, leg cramps, diarrhoea, dehydration and death. Diarrhoea in cholera can be very severe and watery. *Vibrio cholerae* serogroup O1, biotype El Tor and serogroup O139 are responsible for causing cholera with severe symptoms and result in high mortality rates (Sack *et al*. 2003; Centre for Disease Control, 2008b).

2.6.1.3 *Salmonella typhi*

Salmonella typhi is a foodborne bacterial pathogen which causes typhoid fever. People infected with typhoid fever carry the bacteria in the bloodstream and intestinal tract. In some instances, individuals may recover from typhoid fever but may still carry the bacteria. Carriers and infected people shed *Salmonella typhi* in their stool. Typhoid fever is a potentially fatal disease that results in extreme fever, abdominal cramps, flat red spots, headaches and appetite suppression (Centre for Disease Control, 2005).

2.6.1.4 *Shigella* species

Shigella species causes shigellosis. Shigellosis is an infectious disease also known as bacillary dysentery. Four *Shigella* species cause shigellosis: *Shigella dysenteriae, Shigella. flexneri, Shigella boydii, and Shigella sonnei.* Most *Shigella* infections occur via the faecal-oral route. People are infected with foodborne *Shigella* by consuming water or food contaminated by faeces from infected people, eating vegetables grown in fertilizers containing sewage, consuming food contaminated by flies that were bred in *Shigella*-infected faeces and by drinking and swimming in contaminated water. Manifestations of shigellosis are tiredness, fever, abdominal cramps, nausea, vomiting and watery or bloody diarrhoea.

Shigella flexneri is similar to EHEC in that it produces shiga toxin that result in haemolytic uraemic syndrome (Sack, 1997; Centre for Disease Control, 2008c).

2.6.1.5 *Giardia lamblia*

Giardia lamblia is the causative agent of Giardiasis. Giardiasis is a diarrhoeal illness caused by the parasitic protozoan *Giardia lamblia*. This parasite dwells in the intestine of humans and animals. It is passed in the stool of infected individuals. It is transmitted via the faecal-oral route. Upon ingestion the cysts pass into the intestine were they develop and multiply. Eggs are released in the stool of the infected person. These eggs have an outer covering and can remain in the environment for long periods of time. They can also be spread easily in areas were proper hygiene is not practiced. Symptoms of giardiasis are diarrhoea, flatulence, greasy stool that tends to float, stomach cramps and nausea (Centre for Disease Control, 2008d).

2.6.1.6 *Cryptosporidium* species

Cryptosporidium parvum is the causative agent of cryptosporidiosis which can be described as a diarrhoeal disease. Recently it has been shown that *Cryptosporidium intestinalis* also causes cryptosporidosis. The oocysts of this parasite have a hard outer covering thus allowing them to survive outside the body for a long time. This outer shell also makes the parasitic oocyst resistant to chlorine disinfection. *Cryptosporidium* can be transmitted through the oral-faecal route. The most common method of transfer is via the consumption of contaminated drinking water. The oocysts travels to the small intestine were they develop and multiply and new oocysts are then released in the stool. Manifestations of this infection are nausea, watery diarrhoea, malaise, fever, weight loss and abdominal cramps (Centre for Disease Control, 2008e).

2.6.1.7 *Ascaris lumbricoides*

Ascaris lumbricoides (round worm) is a parasitic worm that causes ascariasis. Ascariasis is an infection of the small intestine caused by the roundworm. Roundworm is most common in developing countries where drinking water supplies are limited and of poor quality and sanitation, health and hygiene practices are inadequate. The worm is often transmitted via the faecal-oral route, where hand-washing after defaecation is not a common practice and contamination of soil is common due to the practice of open-defaecation. Drinking water is also easily contaminated when dipping utensils are used to remove water from storage containers. *Ascaris lumbricoides* is a human intestinal parasite which enters the small intestine through ingestion of food or water containing *Ascaris* eggs, from contaminated crops, soil or faecal waste. The eggs form larva in the intestine which are released into circulation and travel to the lung. They leave the lung after three weeks of molting. Thereafter they are coughed up, swallowed and travel via the oesaphagus to the stomach and intestine. There they develop into adult male and female worms. Fertilization occurs and the female can produce approximately 200 000 eggs per day for a year. The eggs are passed out in stool and become infectious in soil in two weeks. Eggs can remain in the soil for three years. In severe cases of ascariasis, intestinal blockages may occur resulting in severe abdominal pain. Fever, wheezing and difficulty in breathing may also occur (Murray *et al.* 2005; Centre for Disease Control, 2008f).

2.7 Relevance to the present study

It is therefore clear that contamination of drinking water with a range of microorganisms can result in ill health and even death. The importance of a study, such as the current study, wherein, the microbial quality of drinking water and its associated physico-chemical properties are analysed and correlated to epidemiological data, serves as a tool to determine if the health outcomes tested (such as diarrhoea and vomiting) are related to drinking water quality solely or if there are any other confounding factors.

In several instances infections caused by the above-mentioned vectors results in vomiting and diarrhoea. It is for this reason that in the epidemiological study, results which are referenced as part of the present study, diarrhoea and vomiting have been used as measures of health with regard to microbial quality of drinking water, sanitation, health and hygiene practices.

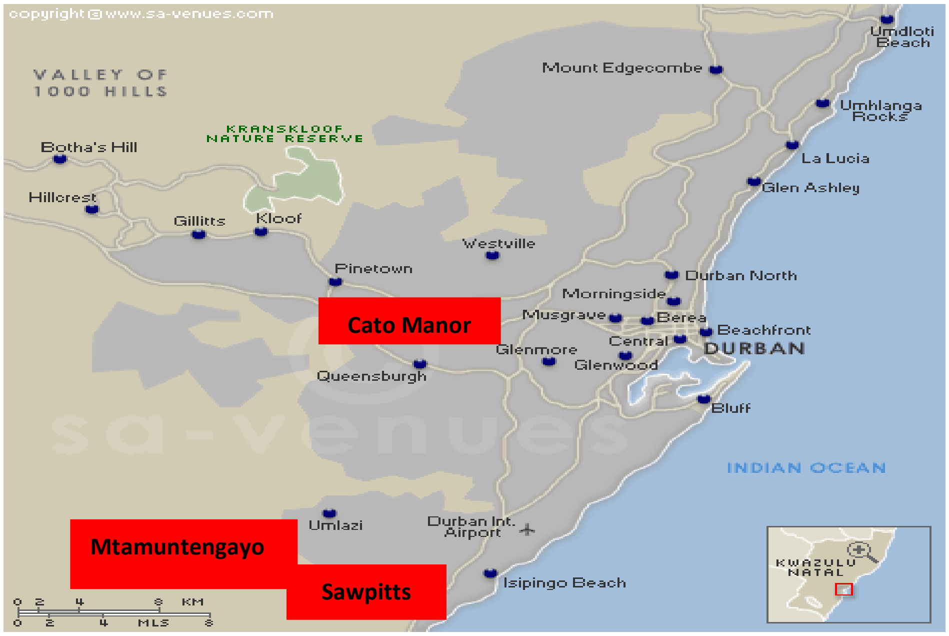
The current microbial water quality study considered the microbial and physico-chemical quality of drinking water. It also made use of information from a study by Lutchminarayan, 2007 on health outcomes, socio-economic status and hygiene and sanitation practices of individuals dwelling in the same households from which drinking water for microbial and physico-chemical analysis was sampled. This information was collated and used to understand if any links existed between the quality of drinking water supplied by eThekwini

Municipality, incidences of health outcomes and hygiene and sanitation practices of individuals dwelling in low-income areas in Durban, South Africa. The current study may also provide insights into the issue of quantity of water versus quality of water and hygiene practices. The microbial and physico-chemical quality of drinking water supplied by eThekwini Municipality was also investigated in order to provide a guide of the current water quality status and to allow for improvements in point-of-use water quality if indicated.

CHAPTER 3: METHODOLOGY

3.1 Background to study sites and water systems analysed

The current study made use of three peri-urban areas as study sites, namely Cato Manor Sawpitts and Mtamuntengayo. The Cato Manor peri-urban settlement is situated approximately 5 km from the Durban city centre. Sawpitts and Mtamuntengayo are approximately 35 km from the Durban city centre. These two latter areas are found approximately 7 km from the Durban International Airport. (Figure 8).



*(Source: www.savenues.com).

Figure 8 Map of Durban illustrating the relative locations of Cato Manor, Mtamuntengayo and Sawpitts.

Each of these areas is located in Durban, South Africa and receives drinking water via semi-pressure and low-pressure water delivery systems (Chapter 2, Figure 1). Below are the areas and the corresponding water delivery systems from which water was analysed (Table 3).

- In Cato Manor drinking water was analysed from on-site ground tanks (ground tanks).
- In Sawpitts drinking water was analysed from ground tanks and community tankers.
- In Mtamuntengayo drinking water was analysed from community tankers (Table 3).

Table 3 Types of water delivery systems sampled in this study and the corresponding area from which samples were taken.

	Cato Manor	**Sawpitts**	**Mtamuntengayo**
Water delivery system used	-Ground tanks -Standpipes	-Ground tanks	-Community tankers

This study compared the microbial and physico-chemical properties of drinking water at the source and its corresponding point-of-use (Figure 9). The source of water in this instance was defined as the origin or starting point from which water supplied to a specific water delivery system originated or stemmed from. It was a sample of water taken from that point in the distribution system that represented treated municipal water (Chapter 1). The point-of-use was defined as the point at which consumers use water from (Chapter 1).

Water from taps at eThekwini Municipality laboratories was taken as representative of source water samples, whilst water from ground tanks in the yard of individual households was sampled as representative of point-of-use water (Figure 9). Taps at eThekwini Municipality were taken as representative of source water since ground tanks were supplied with water from the same municipal distribution system. Since ground tanks serve as both a storage vessel and a dispensing vessel, it was regarded as the point-of-use. Community tankers and standpipes differ in this aspect. This is because these water delivery systems are communal and require that water be collected from the standpipe or tanker, transported to the household and stored until used (Figure 10). Therefore the point-of-use is the storage vessel from which water is used. The source/supply that represents the source of treated municipal water for this storage vessel is the community tankers and standpipes (Figure 9 and Figure 10).

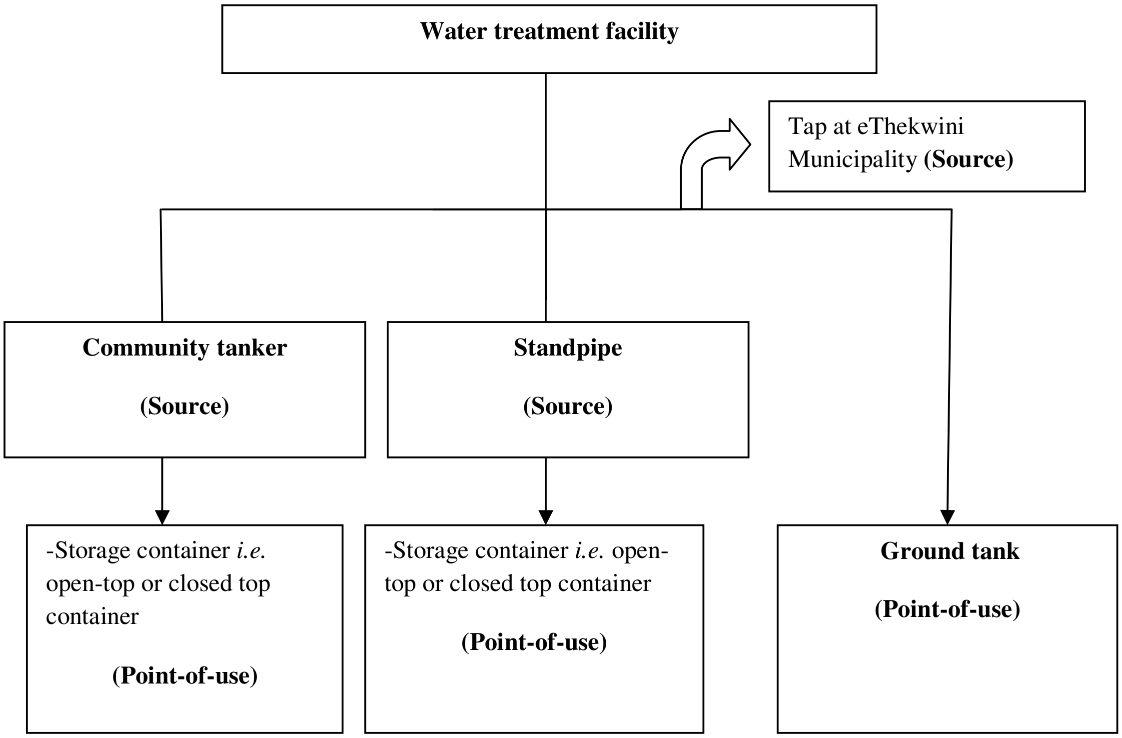


Figure 9 Schematic diagram representing the point-of-use and corresponding source for mobile community tankers, communal standpipes and on-site ground tanks.

Figure 10 explains the flow of water as occurs when water is obtained from communal water sources. Standpipes and community tankers received water from a municipal water treatment plant. This water was then collected from these sources, by users, in either open-top or closed-top storage containers. For purposes of this study, closed-top containers were defined as containers which had a lid that served as a seal from the environment when water was not being used, whilst open-top containers, conversely, were defined as containers which were devoid of a lid and those which were left open during the entire period in which water was stored and used (Chapter 1). The containers filled with water were transported to households after collection. Here, it is stored and used as required (Figure 10)

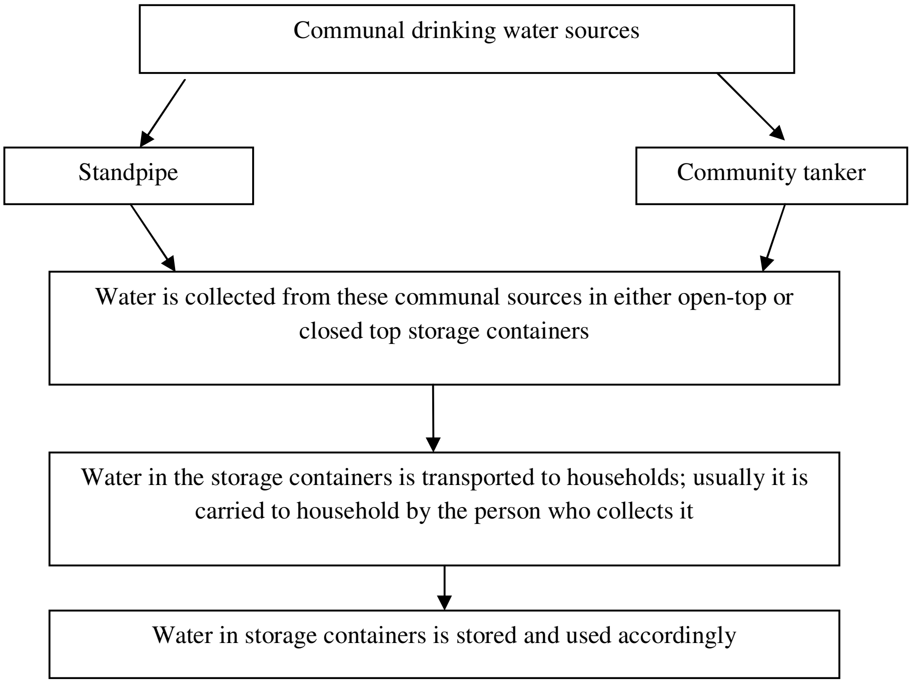


Figure 10 Schematic diagram representing the pathway of water supplied by communal water delivery systems such as standpipes and community tankers.

For the purposes of this study, comparisons were as follows:

- The microbial and physico-chemical quality of drinking water from ground tanks in Sawpitts and ground tanks in Cato Manor were compared. Drinking water from Cato Manor was sampled in 2004 by Maraj (2005). This sampling was done during winter months. Sampling of drinking water from Sawpitts was done by the author and a research team in 2006 during the summer months. Sampling data from both areas were used to compare the microbial and physico-chemical quality of drinking water in these two areas during different seasons. However, a shortfall in the seasonal study was the difference in locations; this is acknowledged and hence this piece of work is presented in the Appendix A.

- The microbial and physico-chemical quality of drinking water from communal water sources *viz*, standpipes in Cato Manor and community tankers in Mtamuntengayo were compared. The reason that standpipes were compared to community tankers rather than to corresponding standpipes was because the same households in Cato Manor could not be sampled due to high mobility of household occupants. A large database of information on Mtamuntengayo was already established at the time of this study (Lutchminarayan, 2007). This allowed for better selection of households with similar socio-economic and demographic properties than those selected in the 2004 study by Maraj *et al*. (2005), in which water from standpipes and storage vessels in Cato Manor were sampled and analysed. Therefore it was decided that Lutchminarayan's (2007) study site would be used and households were selected accordingly. The use of this study site also allowed for addition of information on water quality in these areas, into the existing database. The use of different areas was therefore not viewed as a shortfall of this comparison, since both water sources were communal and household selections in each area was based on exactly the same criteria.

- The microbial and physico-chemical properties of drinking water stored in open-top and closed-top containers in Cato Manor and Mtamuntengayo were compared. These vessels were supplied by either standpipes or community tankers.

- The microbial quality of drinking water at the point-of-use in households comprising adults only (*i.e.* occupants which are > 18 years of age), households including children aged 0-5 years and households including children aged >5-18 years was compared. The purpose of this comparison was to establish if household demographics impacted on the microbial quality of drinking water at the point-of-use.

- The microbial quality of drinking water, health outcomes (diarrhoea and vomiting) and socio-economic status of individuals supplied drinking water by each of the above-mentioned water delivery systems was compared in order to establish if there is a link between water quality, health outcomes, socio-economic status and water-use-behaviour. Data on health outcomes and socio-economic status was obtained from the ECOSAN database.

3.2 Ethics approval

The current study is a water quality study. It aimed to supplement the existing information of an epidemiological study by Lutchminarayan (2007), but it is not itself an epidemiological study. Therefore the ethical approval of the epidemiological study was used for the current study with permission of the owners. The same sites which were used in the epidemiological study were used for the current study. To gain entrance into these areas and hence sample household drinking water, the author and members of the project team went through the eThekwini Municipality community liaison structures. The study was conducted with the permission of the municipal manager (Appendix B) and the community was approached through the eThekwini Water and Sanitation (EWS) community liaison staff and the ward councillor, using members of the communities as facilitators and interpreters. The purpose of the study was explained to each householder and verbal informed consent was obtained before samples were collected at each household. Permission to conduct this study was granted by the eThekwini Municipality manager, this letter is included in Appendix B.

3.3 Household selection

Households were selected based on the type of water delivery system (ground tanks, standpipes, community tankers), household demographics (households including children aged 0-5 years, households including children aged >5-18 years and households comprising adults only) and type of storage containers used to store drinking water in (open-top or closed-top storage containers).

3.3.1 Household selection in Cato Manor

All work in Cato Manor was conducted by Maraj *et al.*, 2005 as part of an Honours dissertation at the University of KwaZulu-Natal. For this study, questionnaires were developed in conjunction with social workers at the University to determine the age of people dwelling in households and to determine the type of water delivery system used. The questionnaire comprised of two sections, a general information section and a section referred to as a diarrhoea diary. The household questionnaire aimed at obtaining general information regarding socio-economic status, type of water delivery system used, type of sanitation practised, type of water storage vessels used, hygiene practices, poverty indices and demographic distributions. The diarrhoea diary was used to record incidences of diarrhoea and duration of diarrhoea in members dwelling in each household. Based on the answers to these questions households were selected as explained above in 3.3.

Maraj (2005) obtained informed consent from every household that agreed to participate in this study. All microbial and physico-chemical analysis was performed by Maraj in conjunction with the staff of eThekwini Municipality Laboratories.

3.3.2 Household selection in Sawpitts and Mtamuntengayo

Household selection in Sawpitts and Mtamuntengayo included the use of the ECOSAN database containing information gathered for a completed Master of Science degree in Epidemiology by Lutchminarayan in 2007.

Lutchminarayan and colleagues performed comparative evaluations on the health impacts of ecological sanitation interventions, water services and hygiene education programmes, individually and in combinations, in eThekwini Municipality, Durban, South Africa. The research aimed to determine whether providing sanitation, safe water and health and hygiene interventions in peri-urban households improved health outcomes.

The database for this study included information from 1350 households. The study design was an observational analytic prospective cohort study between intervention and control groups (Lutchminarayan, 2007). Intervention groups comprised households in which members were given health and hygiene education and which were provided with UD toilets and ground tanks by eThekwini Municipality. Household members were also educated on health and hygiene practices and how to implement proper use and care of UD toilets and ground tanks by eThekwini Municipality staff. The control group comprised households that did not have UD toilets and ground tanks. These households were not educated on health and hygiene practices. They often made use of communal water supplies and stored their drinking water in open-top or closed-top containers. These households used either VIP toilets or practice open defaecation (the bush) for sanitation purposes.

All data in the epidemiological study were collected by means of questionnaire surveys (Lutchminarayan, 2007). Three surveys were used:

- Household questionnaire – The aim of this survey was to gather general information on the socio-economic status of household members, the type of water and sanitation facilities, health and hygiene practices and education levels in households. Details on occupants of the household, number of members in households, age distributions, and possession checklists (to indicate socio-economic status and levels of education) were also recorded.

- Health outcomes questionnaire – The aim of this survey was to determine the rates of diarrhoea, vomiting, skin sores and worms and the duration of such health outcomes in household members participating in the study.

- Observational questionnaire – The aim of this survey was to determine if information given in the household questionnaire corresponded to what was observed in the surroundings. For example, if a respondent indicated that they washed their hands with soap after using a toilet, the observational team member would check if soap was present in the wash area. This served as a method of confirmation of the preceding two questions.

All questionnaire data were captured using EpiData version 2.2. Data were combined and stored on a database program, for statistical analysis.

For the current study, a sample population of 72 households was selected as a subset from the database consisting of 1350 households used in the epidemiological study by Lutchminarayan (2007).

Households were selected according to type of water delivery system used, age distribution within households, and type of storage containers used to store drinking water.

The microbial study was blinded[14], in terms of epidemiological study outcomes. The same methods used in the microbial study by Maraj (2005) were implemented in the current microbial study.

Nine groups were compared to determine if the quality of domestic water supplies was related to health outcomes and socio-economic status (Table 4). Sampling of drinking water and its subsequent microbial and physico-chemical analysis was performed by the author in conjunction with the staff of eThekwini Municipality Laboratories.

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[14] The blind method is a scientific method used to prevent results from being influenced by observer bias or the placebo effect as a result of conscious or unconscious bias (Freund *et al.* 1988; Bacchieri and Cioppa, 2007; Kaptchuk, 2000).

Table 4 Criteria used for sample selection based on demographic composition of household members in Sawpitts and Mtamuntengayo which store drinking water in ground tanks or in open-top or closed-top storage containers respectively. The water source and corresponding point-of-use is also given.

Household demographic group	Area	Water source	Point-of-use samples
Households with children aged 0-5 years Households with children aged >5-18 years Households comprising adults only (>18 years)	Sawpitts	Water samples from eThekwini Municipality taps were taken as representative of source water since ground tanks are supplied with water from the municipal distribution system.	Water stored in ground tanks for 24 hours
Households with children aged 0-5 years Households with children aged >5-18 years Households comprising adults only (>18 years)	Mtamuntengayo	Community tankers	Water stored in open-top containers
Households with children aged 0-5 years Households with children aged >5-18 years Households comprising adults only (>18 years)	Mtamuntengayo	Community tankers	Water stored in closed-top containers

3.4 Sampling

Drinking water was sampled once a day for a total of 10 days at each site. Sampling was done from Monday to Thursday each week, since eThekwini Municipal Laboratories closed on Fridays and samples requiring overnight incubation could not be analysed on weekends. The source and corresponding point-of-use water from ground tank, standpipe and community tanker-supplied households were sampled (Figure 9). Samples were analysed by eThekwini Municipality Laboratories to allow more samples to be analysed than could be handled by the experimenter alone (greater statistical strength of data and the lab followed full quality control procedures including blinding of samples thereby removing any chance of bias).

3.4.1 Sampling from ground tanks

Taps on ground tanks were wiped down with 90% ethanol in order to destroy any bacteria present on taps which could enter drinking water samples and hence provide biased results. Taps were then left to run (flushed) for 1-2 minutes. The purpose of flushing taps was to remove bacteria present in water that was stagnant in the tap region. It is important to practice flushing of taps when collecting drinking water samples for microbial analysis in order to make sure that microbial constituents detected in water samples are representative only of actual water found in the tank rather than the water left to stagnate at the tap region. Water was collected into a 200 ml sterilized Schott bottle. All collection bottles were sealed in foil and sterilized in an autoclave before collection of samples. This served to ensure that all bottles were clean and hence to limit information bias which could occur if sample bottles were contaminated. The foil layer of each bottle was removed by the experimenter, who wore a clean pair of sterile gloves at each sample point, only when samples were ready to be collected. Once the foil layer was removed the neck of the bottle was wiped down with 90% ethanol to remove any contaminants present on the bottle and hence to limit bias with regard to microbial results. A sample was collected from the running tap, the cap of the bottle was closed and the bottle neck was wiped down with 90% ethanol before the sample bottle was stored on ice. It is important to note that at no point during the collection of samples did the gloves of the experimenter touch the tap mouth of the ground tank or any other surrounding region. Following the collection of each sample, gloves were discarded. A new pair of gloves was used in the collection of each sample. All 200 ml Schott bottles contained 3-4 drops of sodium thiosulphate. Sodium thiosulphate served to neutralise residual chlorine in samples to be used for microbial analysis. Removal of residual chlorine in these samples was important so that microbes would not be destroyed by the residual chlorine during transportation to labs and hence a true representation of microbial content in the drinking water sample could be attained. A second sample of drinking water from ground tanks was collected in 100 ml McCartney bottles, in the same manner as explained above. These samples were used to measure the turbidity, conductivity and pH of samples at the eThekwini Municipality laboratory. All samples were placed on ice and transported to the eThekwini Municipality laboratory for analysis. The purpose of ice was to maintain the water temperature in order to prevent changes in pH and, in McCartney bottles, to prevent changes in chlorine levels since chlorine volatilizes at high temperature. A change in temperature would also affect the microbial content, the turbidity and conductivity of samples (Chapter 2).

3.4.2 Sampling from standpipes

The methodology used to sample water from standpipes was the same as methodology used to sample water from ground tanks. Firstly, taps on standpipes were wiped down with 90% ethanol. Thereafter taps were flushed for 1-2 minutes. Water samples were then collected into

200 ml sterilized Schott bottles and 100 ml McCartney bottles for the relevant analysis, as described in 3.4.1.

3.4.3 Sampling from community tankers

Water from community tankers is dispensed into water collection vessels via a tap found on the tanker. Therefore the same sampling methodology was used to collect water samples from community tankers as described in 3.4.1 and 3.4.2.

3.4.4 Sampling of water from storage vessels

After collection, water was stored in either open-top or closed-top storage vessels. Water samples from open-top containers were collected by pouring out drinking water directly from the storage container into the sample collection bottles. Note that, sterile gloves were worn by the sampler at all times. Only sterilized sample bottles were used. Sample bottles were wiped down with ethanol before and after samples were collected. Contact of the neck of the collection bottle with the rim of the container and the hands of the sampler was always avoided. The neck of the sterilized sample bottles was wiped down with 90% ethanol before and after collection. A similar procedure was followed for sampling of water from closed-top containers, the only difference being that the lid of the container was removed, using sterile gloves before water samples were taken.

3.5 Analysis of water samples

All samples were analysed in batches. Technicians were blinded with regard to the origin of samples. Each sample was labelled with a code which could only be tracked by the experimenter.

All water samples were analysed for the following microbes:

- *E. coli*,
- total coliforms and
- heterotrophic organisms.

The following physico-chemical properties of water samples were also measured:

- pH
- water temperature
- turbidity
- conductivity
- total chlorine and
- residual chlorine

3.5.1 Methodology used to enumerate E. coli and total coliforms

Microbial analysis was conducted by the experimenter and eThekwini Municipality laboratory staff. The experimenter assisted in inoculation of agar whilst the eThekwini Municipality laboratory staff prepared agar and conducted colony counts following incubation. Membrane filtration, combined with incubation on specific agar, was used to detect *E. coli* and total coliform bacteria (eThekwini Municipality Test Method Number MM002, 2004). The filtration apparatus consisted of three plastic funnels which fitted onto three filtration stands placed upon a filter manifold. Funnels and filtration stands were sterilized by being boiled in water. The filtration rack was in turn connected via plastic piping to a vacuum pump. Filtrate was collected in a sterile glass bottle. One hundred millilitres of each sample was filtered through a sterile membrane filter with a 0.45µm pore size. Membrane filters were dipped in boiling water prior to placement on the filter units. After each sample was filtered through the apparatus, the apparatus was disassembled, and the funnels sterilized as described. Membrane filters were placed grid upwards on Chromocult® coliform agar (Merck) in a 60 mm plastic petri dish, and incubated in an inverted position at 37^{o}C for 12 hours. This was done in triplicate for all samples. Following incubation, plates were removed and the colonies on the surface of the filter paper were counted. Blue colonies represented *E. coli* colonies, and pink colonies represented total coliform colonies.

The chromogenic substances in Chromocult coliform agar are the cause for the colour differentiation between bacterial colonies formed by *E. coli* and total coliforms. Coliform bacteria contain ß-D-glucuronidase, which cleaves the Salmon-GAL substrate contained within the agar. This results in the formation of a salmon to red colour when observing the coliform colonies. In the case of *E. coli*, the indole reaction, improved by the addition of tryptophane in the medium, is used as a method of confirmation of *E. coli* presence. ß-D-glucuronidase is identified within *E. coli* through use of X-glucuronide. This, together with Salmon-GAL is cleaved by *E. coli*, resulting in the formation of a dark blue to violet colour (eThekwini Municipality, 2004; Satory and Howard, 2008).

Colony numbers were recorded and reported as colony forming units (CFU) per 100 millilitres of sample filtered.

3.5.2 Methodology used to enumerate heterotrophic organisms

The standard pour plate method was used to enumerate heterotrophic organisms (eThekwini Municipality Test Method Number MM007, 2004). Heterotrophic plate count agar (Merck) was prepared prior to use. Agar was sterilised by autoclaving at 120°C for 15 minutes. Agar was melted using a water bath, and removed from heat once it could be held comfortably. Liquid agar was poured into a 90 mm sterile Petri dish, which was inoculated with one millilitre of water sample. The petri dish containing the liquid agar and water sample was swirled to facilitate mixing. Thereafter the agar was allowed to set. Plates were placed in an incubator at a temperature of 37°C for 24 hours. Following incubation, plates were removed from the incubator, and the number of colonies enumerated. These numbers were reported as cfu/ml.

3.5.3 Measurement of physico-chemical parameters

3.5.3.1 Measurement of pH

The pH of all water samples, collected in McCartney bottles, was measured at the eThekwini Municipality laboratory, by the experimenter, using a Metrohm 691 pH meter ®.

3.5.3.2 Measurement of water temperature

Water temperature of all samples was measured on site, by the experimenter, using a thermometer.

3.5.3.3 Measurement of conductivity

Conductivity was measured at the eThekwini Municipality laboratory, by the experimenter, using a Mettler Toledo MC226 conductivity meter ®.

3.5.3.4 Measurement of turbidity

Turbidity was measured at the eThekwini Municipality laboratory, by the experimenter, using a Hach 2100N Turbidimetre ®.

3.5.3.5 Measurement of free and total chlorine

Free and total chlorine levels were measured on site, by the experimenter. This was done by combining either total chlorine or free chlorine reagent (Hanna Instruments) with 10 ml of water sample, using the low and medium range free and total chlorine meter (Hanna Instruments).

3.6 Statistical analysis

All data was analysed using the statistical package SPSS version 15. Ms Tonya Esterhuizen, a qualified statistician from the School of Health Sciences, was consulted for guidance in the selection of appropriate statistical procedures and tests. All statistical analyses were performed by the author in consultation with a biostatistics postgraduate student, Ms Jaclyn Wright.

3.6.1 Statistical analysis of microbial parameters

Three microbial parameters (*E. coli*, total coliforms and heterotrophic organisms) were measured in drinking water.

All data was tested for normality of distribution using the Kolmogrov-Smirnov test. Microbial data was found to be non-normally distributed. Transforming of microbial data was unsuccessful in obtaining normal distribution due to the extreme variability in microbial counts. Microbial data was therefore ranked and subject to non-parametric analysis of variance using the Kruskall-Wallis test with the Tukey post-hoc testing in order to determine:

- The relationship between the microbial quality of drinking water at the source and corresponding point-of-use.
- The relationship between the microbial quality of drinking water from open-top and closed-top storage containers and
- The relationship of the microbial quality of drinking water sampled in summer compared to the quality of drinking water sampled in the winter (Appendix A).

Because distribution of microbial data was typically skewed, one was added to all data in order to be presented in Log form on graphs. Without logging data, graphs would not have been able to be reported as log graphs and would hence be difficult to read since there were numerous low values but a few very high data values which would have masked other values on a non-log scaled graph.

Results include the arithmetic mean, geometric mean and 95th percentile for all microbial data. The reason that each of these statistics was included is explained below.

South African Water quality guidelines (DWAF, 2005) specify frequency of sampling. For communities with a population of less than 2 500, the sampling frequency of once a month is recommended. The communities sampled in this study were in all cases smaller than 2 500 people. Since more than twenty samples were taken per day over a two week period, for each sample group tested, the probability of finding a microbially non-compliant sample was much higher. For this reason, means (arithmetic means and geometric means) were compared to South African Water Quality guidelines and WHO water quality guideline values (DWAF, 1996; DWAF, 2001; WHO, 2005). The value most commonly used for comparison to WHO guidelines is the arithmetic mean (Langmark pers.com), although evaluation of WHO guideline limits is also linked to frequency of sampling.

The arithmetic and geometric means were calculated without adding 1 to the data, as was done during log transformation of data to draw graphs. The geometric mean differs from the arithmetic mean in that whilst the calculation of the arithmetic mean involves the addition of a list of numbers and division of this sum by the total count of numbers in the data set (*n*), the geometric mean is calculated by multiplying the set of numbers and taking the *n*th root of the product. The reason for reporting on both the geometric and arithmetic means in the results chapter (Chapter 4) is that whilst the WHO guideline is often compared to arithmetic mean microbial counts, the geometric mean microbial counts offers better indication of central tendency (Eaton *et al*. 1995; Jagals *et al*. 1999). Hence to develop a holistic view on the risk posed by drinking water, to cause infection in users, the arithmetic and geometric mean microbial counts were compared to guideline values. To further supplement the measure of risk, the 95th percentile of each microbial count was calculated and plotted on graphs, in order to determine and hence report on the upper limit of risk (Kay *et al*. 2003). The 95th percentile values were also compared to guideline values in order to avoid gross underestimation of the risk posed by drinking water to humans in terms of microbial infections, as would be expected from mean values.

3.6.2 Statistical analysis of physico-chemical parameters

All physico-chemical data was tested for normality of distribution using the Kolmogrov-Smirnov test. Data was normally distributed and was tested for significance of differences by one-way-Analysis Of Variance (ANOVA) coupled with least significant difference (LSD) post-hoc tests. Average values for all physico-chemical data are reported.

3.6.3 Statistical analysis to determine the relationship between microbial water quality, health outcomes and socio-economic factors.

All microbial data for each household sampled in Sawpitts and Mtamuntengayo was averaged and merged with the epidemiological data set in order to allow for statistical analysis between microbial and epidemiological data sets. Analysis was performed to define relationships, if any, between:

- Microbial water quality and health outcomes (diarrhoea and vomiting).
- Microbial water quality and social factors.
- Health outcomes and social factors.
- Place (*i.e.* Sawpitts and Mtamuntengayo) versus age of household members and socio-economic factors.

3.6.3.1 Assessing the statistical relationships between microbial water quality and health outcomes.

Four health outcomes (diarrhoea, vomiting, skin sores and worm infestations) were assessed by Lutchminarayan (2007). Only two of these health outcomes (diarrhoea and vomiting) were used in this study. These health outcomes were assessed by recording the number of occurrences of diarrhoea and vomiting in each household. The rate of diarrhoea and vomiting was recorded based on the observation and subsequent reported incidences of these health outcomes by the mother of the household or the main interviewee of a household.

The incidence of each health outcome was calculated as follows and was used in all statistical tests:

$$\textbf{Incidence of health outcome} = \frac{\textbf{Rate of health outcome}}{\textbf{Number of people in each household} \times \textbf{follow up time} \times \textbf{1000}}$$

To investigate relationships between microbial water quality, diarrhoea and vomiting, 3 microbial parameters (*E. coli*, total coliforms and heterotrophic organisms) were used.

To test for significant differences in water quality and in health outcomes among the various points-of-use, water quality data and health outcomes data, were ranked and the Kruskall-Wallis test was conducted on the ranked data, with post hoc testing using the Tukey HSD test. Similarly, to test for significant differences in water quality and in health outcomes among the different age groups, the Kruskall-Wallis test was performed. In addition, to take into account both the effect of age group and of point-of-use water quality simultaneously on health outcomes and the effect of age group on microbial water quality, the Kruskall-Wallis test was performed, using nine groups (Table 3). In order to test for direct relationships between water quality and health, Spearman's rank correlation tests were performed.

Table 5 Categorical division of groups based on age distribution in households and type of storage container used to store drinking water.

Category number	Age distribution	Type of storage container
1	0 – 5 years	Open-top
2	>5– 18 years	Open-top
3	Adults only (>18 yrs)	Open-top
4	0 – 5 years	Closed-top
5	>5 – 18 years	Closed-top
6	Adults only (>18 yrs)	Closed-top
7	0 – 5 years	Ground tanks
8	>5 – 18 years	Ground tanks
9	Adults only (>18 yrs)	Ground tanks

3.6.3.2 Assessing the statistical relationship between socio-economic factors and health outcomes and between socio-economic factors and microbial water quality

To determine significant relationships between socio-economic factors and health, and between socio-economic factors and microbial water quality, Spearman's rank correlation, Mann-Whitney and Kruskall-Wallis statistical tests were used as follows. In cases where the socio-economic factors were quantitative, Spearman's rank correlation was used. Where socio-economic factors were categorical (with 2 categories), Mann-Whitney was used. For more than two categorical groups, the Kruskall-Wallis test was used.

In addition, all microbial parameters (heterotrophic organisms, total coliforms and *E. coli*) were categorised into four quartiles to determine the link between hand-washing and water quality.

3.6.3.3 Assessing the statistical relationships between place/age distribution and socio-economic factors

To test for significant relationships between place or age group, and socio-economic factors, the Mann-Whitney test, the Kruskall-Wallis test and cross tabulations were used as follows. For the relationship between place (Mtamuntengayo and Sawpitts) and quantitative socio-economic factors, the Mann-Whitney test was used. Relationships between age group (households including children aged 0-5 years, >5-18 years and households with adults only), and quantitative socio-economic factors were assessed using the Kruskall-Wallis test. For relationships between place or age group and categorical socio-economic factors, cross tabulations were used. For two by two tables (*i.e.* tables comprising two factors), Fischer's exact statistic was used to determine significant differences, if any, between place, age distribution and socio-economic factors. For larger tables (*i.e.* tables comprising more than two factors), the Chi square statistic was used and assumptions were checked (no less than 20% of expected values <5).

CHAPTER 4: RESULTS

4.1. Point-of-use versus source water quality from ground tanks, standpipes and community tankers

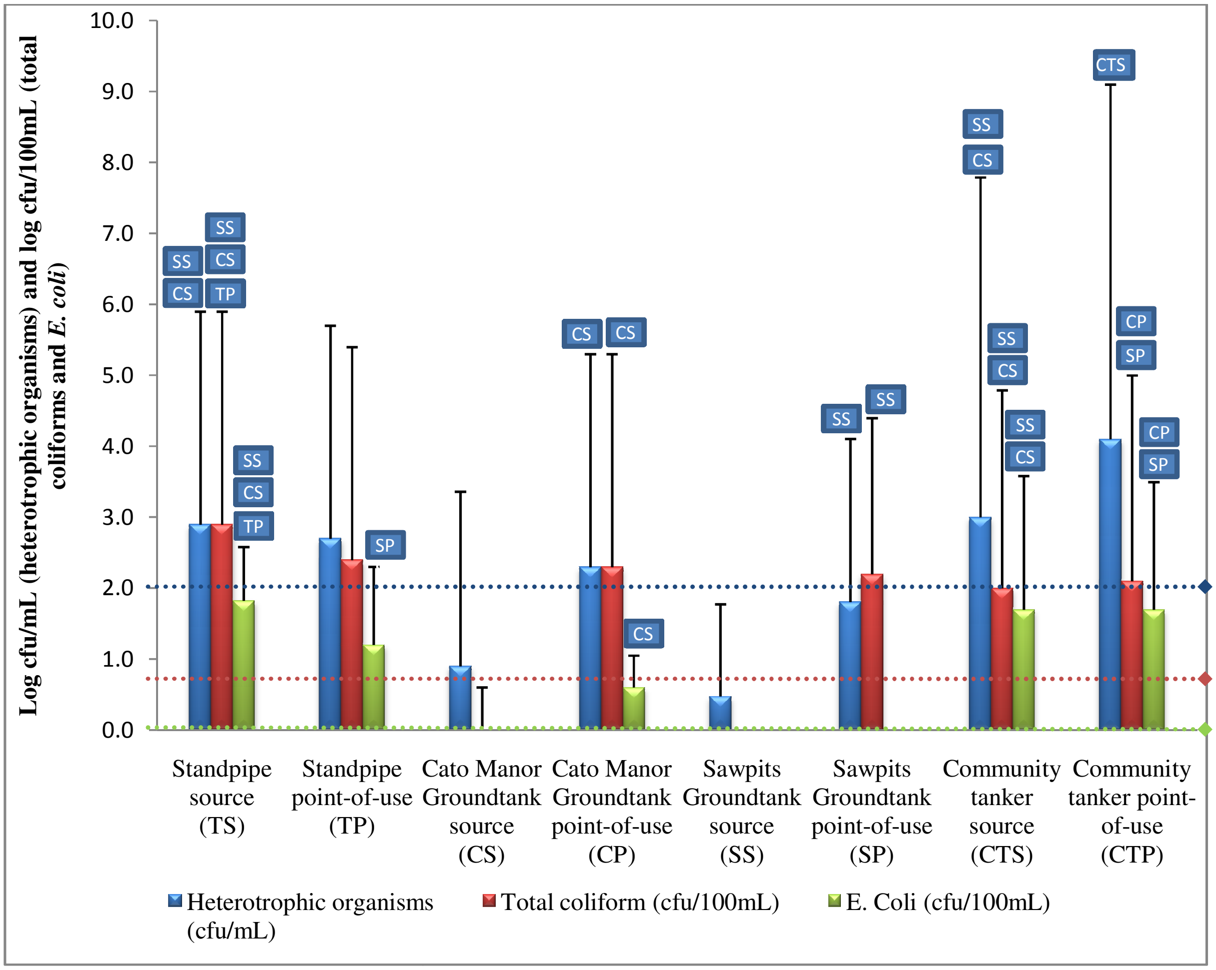
The microbial and physico-chemical quality of drinking water from standpipes, ground tanks and community tankers, at source and at the corresponding point-of-use, supplied to households in Cato Manor and Sawpitts was investigated. The results are presented below.

The DWAF and WHO guidelines for acceptable counts of heterotrophic organisms, total coliforms and *E. coli* and physico-chemical parameters in drinking water are presented in Tables 1 and 2 respectively (Chapter 2).

Measured levels of microbial parameters were compared to guideline values to assess whether water at the point-of-use was fit for consumption, based on risk of microbial infection posed to users as a result of microbe counts in the water.

Water supplied by community water tankers in Mtamuntengayo, had mean *E. coli*, total coliform and heterotrophic organism counts above the acceptable levels for safe drinking water at both source and point-of use (Table 1) (DWAF, 1996; WHO, 2005). Log-transformed counts of heterotrophic organisms, total coliforms and *E. coli* in ground tank households, from Sawpitts and Cato Manor, were significantly higher at the point-of-use compared to the corresponding counts at the source ($p<0.001$ for all microorganisms) (Figure 11). This indicated that untransformed data are also likely to differ significantly. Standpipe source water had higher microbial counts than the corresponding point-of-use water, however only total coliform and *E. coli* counts were significantly higher ($p=0.013$ and $p=0.010$). Community tanker source water had slightly lower, but not significantly so, total coliform counts than the corresponding point-of-use ($p=0.53$). The heterotrophic organisms counts were however significantly higher in point-of-use water than in source water from community tankers ($p=0.013$ for heterotrophic organisms) (Figure 11).

DWAF and WHO maximum levels of heterotrophic organisms, total coliforms and *E. coli*, are given by blue, red and green dotted lines in Figure 11 respectively. These markers show that all water except ground tank source water is unsafe for human consumption and poses a risk of microbial infection to users. If the upper limit of the 95th percentile is taken as the maximum level of risk then maximum risk for all sample groups presented by the 95th percentile is higher than that for the mean risk (Figure 11). Blue boxes indicate where microbial counts are significantly higher in comparison to microbial counts in other source and point-of-use water.



*Error bars represent the 95th percentile. Horizontal lines represent maximum values of heterotrophic organisms (blue), total coliforms (red) and *E. coli* (green) counts allowed in drinking water rendered safe for human consumption. Blue boxes represent significantly higher microbial counts than the sampling point referred to in the box.

Figure 11 Log arithmetic mean microbial counts of source and corresponding point-of-use drinking water from standpipe, ground tank, and community tanker-supplied households.

The 95th percentiles, arithmetic and geometric mean counts of heterotrophic organisms, total coliforms and *E. coli* were compared to South African Water Quality Guidelines and WHO guidelines (Table 1) (reasons for using these statistical measures is discussed in Chapter 3). South African Water Quality Guidelines classify water as posing a negligible risk (NR), potential risk (PR) or substantial risk (SR) of causing infection in users depending on microbial counts of indicator organisms detected for the various source and point-of-use waters (Table 6). It should be noted that a study based purely on counts of indicator microorganisms, such as the present study, strictly only indicates the *risk of contamination*. The necessary factors to determine the *risk of infection* (e.g. presence of pathogens, exposure of consumers to pathogens, infectivity and susceptibility) were not investigated. However, the DWAF guidelines, used to evaluate water quality here, link levels of microorganisms to a probable risk of infection. Comments made on risk of infection or illnesses are based purely on this guideline recommendation.

The upper limit of the 95th percentile for heterotrophic organisms, total coliforms and *E. coli* placed drinking water from standpipe source, standpipe point-of-use, Cato Manor ground tank point-of-use, community tanker source and corresponding point-of-use water in the substantial risk of causing microbial infection to user's category (Figure 11). The upper limit of risk of the 95th percentile for source water from ground tanks in Sawpitts shows that this is the only water which is safe for human consumption with regard to all three microbial parameters (Figure 11).

Arithmetic and geometric mean microbial counts for standpipe source and point-of-use water posed a potential risk of microbial infection to users in one parameter (HPC) and a substantial risk of microbial infection to users in two parameters (total coliforms and *E. coli*) (Table 6). Ground tank source water in Cato Manor and Sawpitts had overall mean microbial counts (*i.e.* both geometric and arithmetic mean counts for HPC, total coliforms and *E. coli*) that posed a negligible risk of microbial infection to users (Table 6). Ground tank-supplied point-of-use drinking water in Cato Manor posed a potential risk of microbial infection to users in two microbial parameters (HPC and *E. coli*)) and a substantial risk of microbial infection to users in one microbial parameters (total coliforms), according to arithmetic and geometric mean microbial counts (Table 6). In Sawpitts, the arithmetic and geometric mean counts of total coliforms and *E. coli* posed a substantial risk of microbial infection and a potential risk of infection to users respectively, whilst the HPC arithmetic mean value posed a negligible risk of infection to users and the HPC geometric mean counts posed a potential risk of infection to users (Table 6). Thus far in comparing geometric and arithmetic means, this is the first instance in which the counts display differing results. Source and point-of-use drinking water from community tankers had arithmetic and geometric mean counts of HPC, total coliforms and *E. coli* that posed a substantial risk of causing microbial infection in users (Table 6).

In comparison to ground tank source water, source water from standpipes and community tankers showed a worse quality (Figure 11), falling into the category of substantial risk for *E. coli* and total coliform counts with regard to the geometric and arithmetic mean (Table 6). Water at the point-of-use from ground tanks displayed significant deterioration in microbial quality in comparison to the corresponding source water in all three microbial parameters ($p=0.012$ for heterotrophic organisms, $p<0.001$ for total coliforms and $p<0.001$ for *E. coli*). Water at the point-of-use from standpipes did not display further significant deterioration in microbial quality relative to its source water ($p=0.536$ for heterotrophic organisms, $p=0.153$ for total coliforms and $p=0.10$ for *E. coli*). Point-of-use water from community tankers displayed a significant deterioration in microbial quality, only in terms of heterotrophic organism counts ($p=0.013$) when compared to its corresponding source water quality (Table 6 and Figure 11).

Overall when comparing risk levels associated with arithmetic mean, geometric mean and 95th percentiles, all three statistical measures rendered the same risk of infection categories for

- total coliform counts in all source and point-of-use water samples;
- *E. coli* in all standpipe source and point-of-use water;
- *E. coli* in ground tank point-of-use water in Sawpitts;
- *E. coli* in community tanker and source water;
- Heterotrophic organisms in community tanker source and point-of-use water; and
- Heterotrophic organisms in ground tank source water in Sawpitts.

The upper limit of the 95th percentile for heterotrophic organisms differed from the arithmetic and geometric mean risk levels for standpipe and ground tank water in Cato Manor. Here, drinking water posed a higher level of risk of microbial infection to users in comparison to the level of risk derived from either the geometric or arithmetic means.

Table 6 Arithmetic mean (AM) and geometric mean (GM) microbial counts from source and point of-use water in all sample groups and areas (heterotrophic plate count (HPC) in cfu/mL; total coliforms and *E. coli* in cfu/100mL.

Area			HPC (cfu/ml)	Risk	Total coliform (cfu/ml)	Risk	*E. Coli* (cfu/ml)	Risk
Standpipes	**Source (community standpipes)**	**AM**	**794**		**794**		**67**	
		n[d]=	40	**PR[b]**	40	**SR[c]**	40	**SR**
		GM	**902**		**900**		**210**	
		n=	38	**PR**	34	**SR**	33	**SR**
	Point of use (containers in household)	**AM**	**501**		**251**		**16**	
		n=	480	**PR**	480	**SR**	480	**SR**
		GM	**640**		**430**		**95**	
		n=	344	**PR**	300	**SR**	54	**SR**
Ground tanks Cato Manor	**Source (laboratory tap)**	**AM**	**8**		**0**		**0**	
		n=	9	**NR[a]**	9	**NR**	9	**NR**
		GM	**25**		**0**		**0**	
		n=	5	**NR**	0	**NR**	0	**NR**
	Point-of-use (water dispensed from tap on ground tank)	**AM**	**199**		**199**		**4**	
		n=	267	**PR**	267	**SR**	267	**PR**
		GM	**360**		**290**		**8**	
		n=	184	**PR**	132	**SR**	25	**PR**
Ground tanks Sawpits	**Source (laboratory tap)**	**AM**	**3**		**0**		**0** 4	
		n=	40	**NR**	40	**NR**	0	**NR**
		GM	**12**		**0**		**0**	
		n=	5	**NR**	0	**NR**	0	**NR**
	Point-of-use (water dispensed from tap on ground tank)	**AM**	**64**		**158**		**1**	
		n=	280	**NR**	280	**SR**	280	**PR**
		GM	**160**		**110**		**5**	
		n=	131	**PR**	92	**SR**	34	**PR**
Community tankers	**Source (water dispensed from tanker)**	**AM**	**10 000**		**100**		**50**	
		n=	68	**SR**	68	**SR**	68	**SR**
		GM	**14 000**		**250**		60	
		n=	63	**SR**	56	**SR**	43	**SR**
	Point-of-use (containers in household)	**AM**	**12 589**		**126**		**50**	
		n=	480	**SR**	480	**SR**	480	**SR**
		GM	**127 000**		**240**		**96**	
		n=	231	**SR**	147	**SR**	62	**SR**

[a]NR-negligible risk.
[b]PR- potential risk.
[c]SR- substantial risk).
[d]n represents the number of samples used to derive mean values.

Results for physico-chemical measurements are given in Table 7 below. All standard values for physico-chemical properties are given in Table 2. The pH in all groups was within limits recommended by DWAF and WHO guidelines (Table 2, Chapter 2). Residual chlorine levels in water from ground tanks and standpipes in Cato Manor were within recommended levels of 0.2 to 1.5 mg/L (DWAF, 1996; WHO, 2005). However, residual chlorine levels in point-of-use water from community tankers and Sawpitts ground tank households were below recommended levels in DWAF and WHO guidelines (Table 7).

Total chlorine levels in all groups were below the recommended levels of 2 to 2.5 mg/L. Turbidity in all groups except source water for community tankers was within the recommended levels of 1–5 NTU. Conductivity in all sample groups was within the guideline levels of 100mS/m (DWAF, 1996; DWAF, 2005; WHO, 2005) (Table 7).

High turbidity, in this instance, was associated with low residual and total chlorine levels and lower conductivity levels. The highest turbidity was observed in communal water sources (standpipes and community tankers) and the associated point-of-use water, whether stored in open-top or closed-top containers (Table 7).

The standard deviation and number of data points used for all physico-chemical parameters is also given in Table 7. The standard deviation for pH, residual and total chlorine in all sample groups was below one. This indicated low level of dispersion of data. Turbidity in water samples from all sample groups except, standpipe and community tanker point-of-use water had a standard deviation less than one. The higher standard deviation as occurred in standpipe and community tanker households represents the high level of dispersion of this data. It implies that few households may have had very high turbidity values whilst a larger number of these households may have had low turbidity values.

The standard deviation for conductivity values for water sampled from all point-of-use and sources was above one except in ground tank point-of-use water.

Table 7 Average pH, residual Cl (mg/L), total Cl (mg/L), turbidity (NTU) and conductivity (mS/m) for all source and point-of-use water samples.

Sample groups		pH	Residual chlorine (mg/L)	Total Chlorine (mg/L)	Turbidity (NTU)	Conductivity (mS/m)
Standpipes	**Source (community standpipes)**	**7.88**	**0.37**	**0.51**	**0.74**	**14.74**
	n[a] =	40	40	40	40	40
	SD[b]=	0.10	0.11	0.17	0.52	2.7
	Point of use (containers in household)	**7.92**	**0.23**	**0.36**	**1.1**	**15.34**
	n =	480	480	480	480	480
	SD =	0.14	0.14	0.20	2.2	2.7
Ground tanks Cato Manor	**Source (laboratory tap)**	**8.13**	**0.28**	**0.49**	**0.51**	**25.84**
	n =	9	9	9	9	9
	SD =	0.14	0.17	0.19	0.64	1.8
	Point-of-use (water dispensed from tap on ground tank)	**7.99**	**0.38**	**0.57**	**0.66**	**14.91**
	n =	267	267	267	267	267
	SD =	0.20	0.41	0.35	0.29	1.23
Ground tanks Sawpitts	**Source (laboratory tap)**	**7.56**	**0.16**	**0.57**	**0.03**	**10.24**
	n =	40	40	40	40	40
	SD =	0.30	0.08	0.09	0.9	1.27
	Point-of-use (water dispensed from tap on ground tank)	**8.08**	**0.07**	**0.1**	**0.53**	**12.41**
	n =	280	280	280	280	280
	SD =	0.11	0.52	0.08	1.0	0.82
Community tankers	**Source (water dispensed from tanker)**	**8**	**0**	**0.06**	**7.22**	**11.4**
	n =	68	68	68	68	68
	SD =	0.12	0.51	0.48	1	1.1
	Point-of-use (containers in household)	**8**	**0**	**0.13**	**1.49**	**6.62**
	n =	480	480	480	480	480
	SD =	0.15	0.15	0.47	5.4	6.2

[a] n represents the sample size.

[b] SD represents the standard deviation.

4.2. Open-top storage containers versus closed-top storage containers

Water from communal sources (standpipes and community tankers) was collected in either open-top or closed-top containers. Once filled, containers were transported to households where they were stored till ready for use. Presented below are microbial and physico-chemical results and analysis of water collected from open-top or closed-top storage containers (defined in Chapter 1), at the household level, which were supplied drinking water by communal water delivery systems (standpipes and community tankers) (Figure 12 and Table 8).

The overall microbial quality of water from standpipes (source water) was worse than the microbial quality of water from open-top and closed-top containers which they supplied. Heterotrophic organisms counts were slightly, but not significantly, higher in standpipe source water in comparison to water from standpipe-supplied open-top and closed-top containers (p=0.387 and p=0.556 for HPC in closed-top and open-top containers, respectively). Standpipe source water had significantly higher total coliform counts than water from open-top and closed-top storage containers which were supplied by standpipes (p=0.035 and P=0.032 respectively). Standpipe source water had significantly higher *E. coli* counts than water from open-top and closed-top storage containers which were supplied by standpipes (P=0.025 and P=0.021 respectively). Since no further deterioration in water quality between the source and point-of-use, for standpipe-supplied households, was noted it can be implied that the poor microbial quality of drinking water from standpipes is a major contributing factor to the poor microbial quality of point-of-use water (open-top and closed-top containers) (Figure 12).

Standpipe-supplied households displayed slightly, but not significantly higher, *E. coli* and total coliform counts in water stored in open-top containers than in water from closed-top containers (p=0.730 and p=0.215 respectively). However, standpipe-supplied households using closed-top storage containers had slightly, but not significantly, higher HPC counts in water at the point-of-use than households using open-top storage containers (p=0.601) (Figure 12).

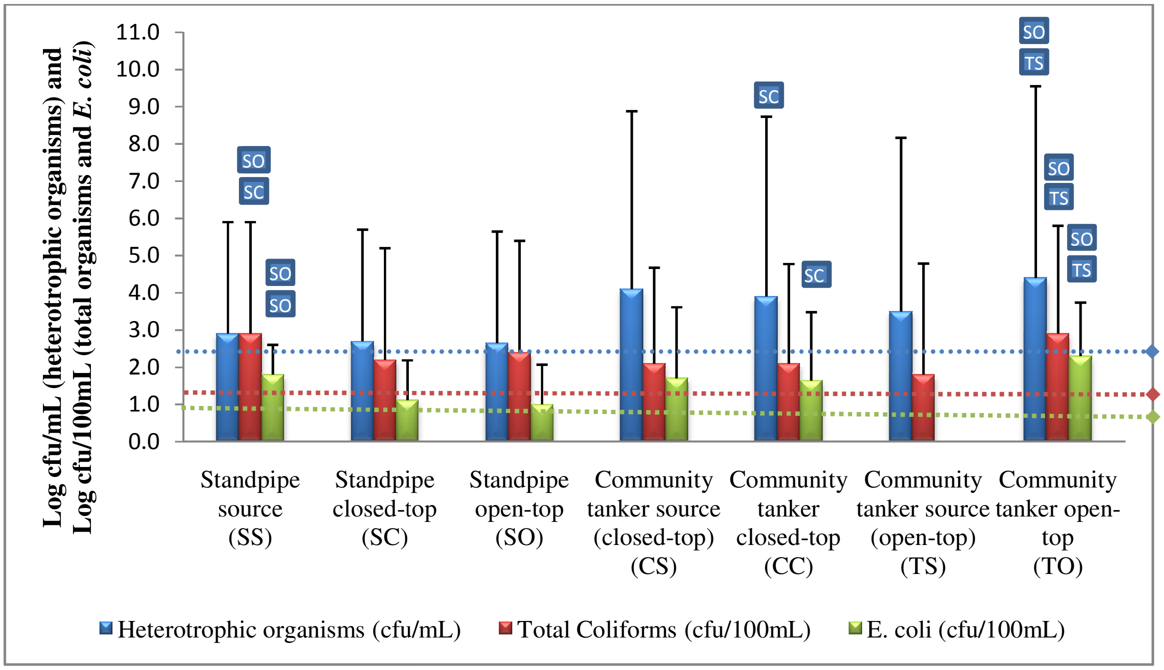
As described in the methods chapter (Chapter 3), different containers were sampled, as representatives of source water, for open-top and closed-top storage tankers. Therefore when referring to community tanker source (closed-top) the inference is that these tankers were sampled as the source water on the day that water from closed-top containers was sampled and *vice versa* for open-top containers. Community tankers which served as the source for closed-top water storage containers showed similar overall microbial counts to water from closed-top containers (Figure 12). There was no increase in microbial counts noted in water from closed-top storage containers supplied by community tankers when compared to the source. This again suggests that, the poor microbial quality of point-of-use water was the result of poor source water quality. This also indicates that the use of closed-top storage vessels may limit further microbial deterioration of drinking water at the point-of-use and during transportation of water to households (Figure 12).

According to statistical testing, water from community tankers which served as the source for open-top storage containers had significantly lower HPC, total coliform and *E. coli* counts than water from the corresponding open-top storage containers which they supplied ($p<0.001$, $p=0.003$ and $p<0.001$ respectively). Water sampled from these open-top storage containers showed significant deterioration in microbial water quality in comparison to its corresponding source water. This suggests that microbial contamination of point-of-use water samples stored in open-top containers may be due to contamination during transport or storage of water in addition to poor quality of source water.

Generally, in community tanker-supplied households, water from open-top containers showed higher microbial counts than water from closed-top containers (Figure 12), with total coliform and *E. coli* counts being significantly higher in water from open-top containers in comparison to water from closed-top containers ($p=0.001$ and $p=0.031$ respectively).

Water from community tanker-supplied households using open-top storage containers showed significantly poorer water quality than did water from standpipe-supplied households using open-top water storage containers ($p<0.001$ for HPC, total coliforms and *E. coli*) (Figure 12 and Table 8). Water from community tanker-supplied households using closed-top storage containers showed significantly higher HPC and *E. coli* counts in comparison to water from closed-top containers supplied by standpipes ($p<0.001$ for HPC and *E. coli*). Therefore the microbial quality of community tanker-supplied point-of-use water was worse than that of standpipe-supplied point-of-use water. Overall, it has been shown that the quality of source water and the use of open-top or closed-top water storage containers both contribute towards poor microbial quality of drinking water at the point-of-use.

DWAF guideline values for maximum number of heterotrophic organisms (blue), total coliforms (red) and *E. coli* (green) allowed in drinking water are presented in Figure 12 below. The markers on the graph indicate that all communal source (standpipe and community tanker) and point-of-use (open-top and closed-top containers) water samples are unsafe for human consumption and pose a level of risk of microbial infection to users due to the high microbial counts, which exceeded guideline maximum values, in water tested. The upper limit of all 95th percentiles suggests that the risk of infection posed to users by drinking water in this instance is substantial. Blue boxes indicate where microbial counts are significantly higher in water sampled from either the source, closed-top containers or open-top containers supplied by either standpipes or community tankers.



*Error bars represent the 95th percentile. Horizontal lines represent maximum values of heterotrophic organisms (blue), total coliforms (red) and *E. coli* (green) counts allowed in drinking water rendered safe for human consumption. Blue boxes represent significantly higher microbial counts than the sampling point referred to in the box.

Figure 12 Log arithmetic mean microbial counts in water from standpipe and community tanker-supplied households using either open-top or closed-top containers for storage of drinking water.

Table 8 gives the comparison of guideline values to arithmetic and geometric mean microbial counts as discussed previously (Chapter 3). Both, arithmetic and geometric mean microbial counts for standpipe source and point-of-use samples posed a potential risk of microbial infection to users in one parameter (HPC) and a substantial risk of microbial infection to users in two parameters (total coliforms and *E. coli*). All community tanker source and point-of-use water posed a substantial risk of microbial infection to users in three parameters (HPC, total coliforms and *E. coli*) with the exception of community tankers supplying open-top storage containers which had overall geometric and arithmetic mean counts of *E. coli* which placed it in the category for negligible risk of causing microbial infection (Table 8). No differences were noted between risk categories when comparing geometric and arithmetic means (Table 8).

The level of risk associated with the upper limit of all 95th percentile values for total coliforms and *E. coli* counts in water from all communal sources and points-of-use posed the same risk of microbial infection to users as did the arithmetic and geometric mean microbial counts in the same water (Figure 12, Table 8). The upper limit of 95th percentile values for heterotrophic organism counts also posed the same level of risk of infection in users as did arithmetic and geometric mean microbial counts for water from all community tanker and corresponding source samples. The only instance in which the upper limit of risk associated with 95th percentile values differed from risk associated with arithmetic and geometric mean microbial counts was in the case of standpipe source and point-of-use samples. Here, heterotrophic organism counts in water posed a substantial risk of infection to users according to the upper limit of risk associated with the 95th percentile whilst arithmetic and geometric means suggested that heterotrophic organism counts only posed a potential risk of infection to users.

Table 9 shows the physico-chemical analysis for standpipe source and point-of-use samples and for community tanker source and point-of-use samples. Measured values for pH, conductivity and turbidity for all sample groups were within limits specified in DWAF and WHO guidelines (Chapter 2, Tables 1 and 2) (Table 9). Total chlorine levels were below the recommended levels of 2 to 2.5 mg/L for all sample groups. Residual chlorine levels were below recommended levels of 0.2 to 1.5 mg/L in all community tanker sample groups. Standpipe source and point-of-use sample groups had residual chlorine levels just above the recommended levels (Table 9).

Table 8 Arithmetic mean (AM) and geometric mean (GM) microbial counts in water from standpipe and community tanker supplied households using open-top or closed-top containers for water storage (heterotrophic plate counts (HPC) in cfu/mL; coliforms and *E. coli* in cfu/100mL) as compared to DWAF guidelines for water quality for domestic use.

Sample group		HPC (cfu/mL)	Risk	Total Coliforms (cfu/100mL)	Risk	*E. coli* (cfu/100mL)	Risk
Standpipe source	**AM** **n[d]=**	**794** 40	**PR[b]**	**794** 40	**SR[c]**	**63** 40	**SR**
	GM **n=**	**902** 38	**PR**	**900** 34	**SR**	95 23	**SR**
Standpipe closed-top	**AM** **n=**	**501** 240	**PR**	**158** 240	**SR**	**13** 240	**SR**
	GM **n=**	**620** 238	**PR**	**430** 56	**SR**	**71** 53	**SR**
Standpipe open-top	**AM** **n=**	**446** 240	**PR**	**251** 240	**SR**	**10** 240	**SR**
	GM **n=**	**650** 240	**PR**	**440** 59	**SR**	**110** 62	**SR**
Community tanker source (closed-top)	**AM** **n=**	**12 589** 34	**SR**	**125** 34	**SR**	**50** 34	**SR**
	GM **n=**	**15 000** 34	**SR**	**130** 29	**SR**	**60** 30	**SR**
Community tanker (closed-top)	**AM** **n=**	**7 943** 240	**SR**	**125** 240	**SR**	**44** 240	**SR**
	GM **n=**	**17 000** 239	**SR**	**150** 97	**SR**	**57** 60	**SR**
Community tanker source (open-top)	**AM** **n=**	**3 162** 34	**SR**	**63** 34	**SR**	**0** 34	**NR[a]**
	GM **n=**	**13 000** 34	**SR**	**510** 21	**SR**	**0** 0	**NR**
Community tanker (open-top)	**AM** **n=**	**25 118** 240	**SR**	**794** 240	**SR**	**200** 240	**SR**
	GM **n=**	**255 000** 240	**SR**	**902** 212	**SR**	**250** 192	**SR**

[a] NR-negligible risk.
[b] PR- potential risk.
[c] SR- substantial risk).
[d] n represents the number of samples used to derive mean values.

The standard deviation and number of data points for all physico-chemical properties is illustrated below in Table 9. Standard deviation for pH, residual chlorine and total chlorine for all sample groups was below the recommended level of one, thus indicating a good level of dispersion of data. The standard deviation for turbidity was above one for water from open-top containers supplied by standpipes and ground tanks. The standard deviation for conductivity was above one for water from all standpipe sample groups and for water from open-top containers supplied by community tankers.

Table 9 Average pH, free Cl (mg/L), residual Cl (mg/L), turbidity (NTU) and conductivity (mS/m) for all source and point-of-use water samples.

Sample groups		pH	Residual chlorine (mg/L)	Total Chlorine (mg/L)	Turbidity (NTU)	Conductivity (mS/m)
Standpipe source		**7.9**	**0.4**	**0.5**	**0.7**	**15**
	n[a]	40	40	40	40	40
	SD[b]	0.1	0.11	0.17	0.52	2.7
Standpipe container (Closed-top)		**7.9**	**0.2**	**0.3**	**1.1**	**15**
	n	240	240	240	240	240
	SD	0.13	0.14	0.19	1.0	2.8
Standpipe container (Open-top)		**7.9**	**0.2**	**0.4**	**1.2**	**16**
	n	240	240	240	240	240
	SD	0.13	0.15	0.21	2.4	2.8
Tanker source (for samples from closed-top containers)		**8.1**	**0.03**	**0.07**	**1.7**	**12**
	n	34	34	34	34	34
	SD	0.08	0.04	0.07	0.22	0.56
Tanker container (Closed-top)		**8.1**	**0.07**	**0.2**	**0.78**	**13**
	n	240	240	240	240	240
	SD	0.1	0.16	0.64	0.21	0.73
Tanker source (for samples from open-top containers)		**8.1**	**0.04**	**0.06**	**2.6**	**11**
	n	34	34	34	34	34
	SD	0.14	0.63	0.98	0.37	0.18
Tanker container (Open-top)		**8**	**0.07**	**0.1**	**1.9**	**12**
	n	240	240	240	240	240
	SD	0.19	0.14	0.19	1.41	3.1

[a] n represents the number of samples used to derive mean values.

[b] SD represents the standard deviation.

4.3. Distribution of household demographics and its impact on the microbial quality of drinking water

The following results comprise information on the microbial and physico-chemical properties of drinking water sampled from three sample groups:

- Households including children aged 0-5 years

- Households including children aged >5-18 years and
- Households comprising adults only (>18 years).

Each of these groups was supplied with drinking water by standpipes, ground tanks or community tankers. The purpose of this was to establish if household demographics had an impact on the microbial quality of drinking water. The microbial content of drinking water sampled from households comprising each of the three groups is given in Figure 13.

Community tanker-supplied drinking water sampled from open-top and closed-top containers from all three sample groups (households including children aged 0-5 or >5-18 years and households comprising adults only) had significantly higher HPC counts than drinking water supplied by standpipes or ground tanks to households comprising any of the 3 sample groups ($p<0.001$ for all).

Drinking water supplied by standpipes and Cato Manor ground tanks had higher, but not significantly higher, HPC counts in water sampled from households comprising adults only than from households including children (Figure 13). This however, differed for community tanker and Sawpitts ground tank-supplied drinking water. In Sawpitts it was found that the highest HPC counts occurred in drinking water sampled from households including children aged 0-5 years, whilst in community tanker-supplied households the highest HPC counts occurred in drinking water sampled from households including occupants aged >5-18 years. Age distribution in this instance showed no specific association with the presence of heterotrophic organisms. Microbial content of drinking water varied with the age of household occupants and with the type of water supply system used (Figure 13).

Standpipe-supplied households had the highest, but not significantly so, *E. coli* and total coliform counts in water sampled from households including children aged >5-18 years in comparison to water from homes having adults only or children aged 0-5 years (Figure 13). In Cato Manor, the highest *E. coli* and total coliform counts in drinking water occurred in samples taken from households including children aged 0-5 years. These values were not significantly higher than *E. coli* and total coliform counts in drinking water samples from households including occupants aged >5-18 years, however *E. coli* counts in water from households including children aged 0-5 years and in households including children aged >5-

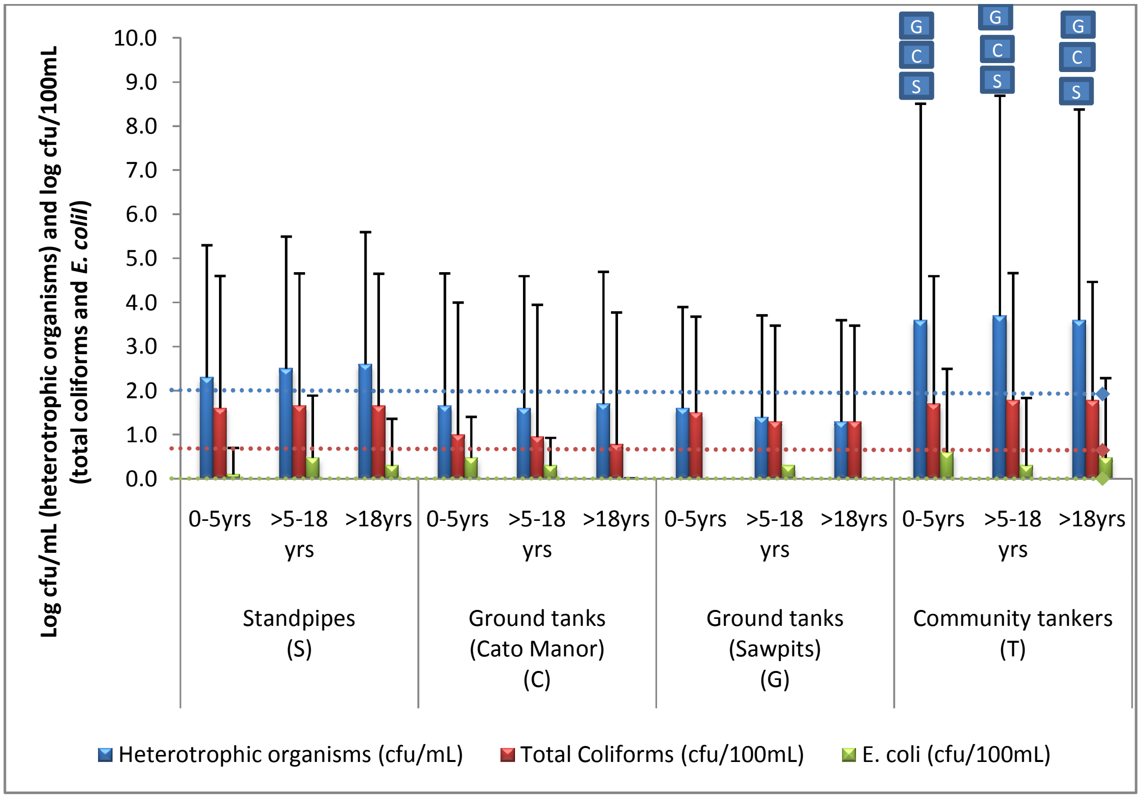
18 years was significantly higher than *E. coli* counts in water sampled from households comprising adults only.

Ground tank-supplied households in Sawpitts had the highest, but not significantly so, *E. coli* counts in drinking water samples from households including children aged >5-18 years and the highest total coliform counts in drinking water samples from households including children aged 0-5 years in comparison to drinking water samples from homes comprising adults only (*i.e.* households having no members under the age of 18 years). The converse applied for drinking water samples from households supplied by community tankers. Households supplied by community tankers had the highest, but not significantly so, *E. coli* counts in water samples from homes including children aged 0-5 years and the highest total coliform counts in water samples from homes including children aged >5-18 years (Figure 13).

The trend for faecal contaminants (*E. coli* and total coliforms) was that water from households including children (either aged 0-5 or >5-18 years) generally had higher, but not significantly higher, *E. coli* and total coliform counts than water from households comprising adults only (>18 years of age).

This implies that faecal contamination of drinking water may be associated with the presence of children in a household. Microbial counts in water sampled from Cato Manor ground tank and community tanker-supplied households including the 0-5 year age group had the highest overall *E. coli* counts (Figure 13).

According to the guideline markers on Figure 13, heterotrophic organisms (blue) and *E. coli* (green) counts exceed maximum allowed levels in DWAF guidelines for water from standpipes and community tankers in samples taken from homes including all three age groups. Total coliform counts in water from any of the delivery systems, and for any age group, tested exceeded guideline values (Figure 13). Therefore water from standpipes, ground tanks and community tankers posed a risk of microbial infection to users with regard to heterotrophic bacteria and total coliform counts. Community tanker water posed the highest risk of microbial infection to users as presented by the upper limit of the 95th percentile shown as error bars on the graph (Figure 13). Blue boxes on the graph indicate where microbial counts are significantly higher than sampling points referred to in the box.



*Error bars represent the 95th percentile. Horizontal lines represent maximum values of heterotrophic organisms (blue), total coliforms (red) and *E. coli* (green) counts allowed in drinking water rendered safe for human consumption. Blue boxes represent significantly higher microbial counts than the sampling point referred to in the box.

Figure 13 Log arithmetic mean microbial counts of heterotrophic organisms, total coliforms and *E. coli* in drinking water supplied by community tankers, standpipes and ground tanks (ground tanks in Cato Manor and Sawpitts). Households are distinguished by age distribution of household members (*i.e.* households including children aged 0-5 years, households including children aged 5-18 years and households consisting of individuals over the age of 18 (adults).

The upper limit of risk associated with 95th percentile values differed from arithmetic mean and geometric mean microbial risk levels in the following way:

- Drinking water samples from standpipe-supplied households including occupants of all age groups tested had heterotrophic organism counts that posed a substantial risk of microbial infection to users whilst arithmetic means posed a potential risk of microbial infection to users in all three microbial parameters. Geometric mean microbial counts, however posed a potential risk of infection to users in one parameter (HPC) and a substantial risk of infection to users in two parameters (total coliforms and *E. coli*) (Figure 13 and Table 10).

- Heterotrophic organism and total coliform counts in drinking water from ground tanks in Cato Manor and Sawpitts posed a substantial risk of infection to users, with regard to the upper limit of risk represented by the 95th percentile, whilst arithmetic means posed a negligible risk and geometric means posed a potential risk of microbial infection to users (Figure 13 and Table 10).

All geometric mean and 95th percentile values representing all three microbial parameters in community tanker water, for all age groups, posed a substantial risk of infection to users (Figure 13, Table 10).

Table 10 comprises arithmetic and geometric mean microbial counts in drinking water sampled from standpipe, ground tank and community tanker-supplied households including children aged 0-5 years, children aged >5-18 years and households including occupants aged >18 years (also referred to in text as adults). The arithmetic and geometric means were used to compare point-of-use microbial drinking water quality to the South African and WHO water quality guidelines for drinking water (DWAF, 1996; WHO, 2005). The WHO and DWAF microbial guideline values are presented in Chapter 2 (Table 1).

The risk of microbial infection associated with HPC counts in standpipe-supplied households, according to the arithmetic and geometric mean, showed that water posed a potential risk of microbial infection to users in all three age groups. The arithmetic and geometric mean results however differed in terms of the risk category for total coliforms and *E. coli*. Whilst the arithmetic mean of total coliform and *E. coli* counts showed that water from standpipe-supplied households posed a potential risk of microbial infection to users, in all three demographic groups, geometric mean microbial counts of total coliform and *E. coli* showed that water posed a substantial risk of microbial infection to users in all three demographic groups (Table 10).

Drinking water samples from ground tank-supplied households in Cato Manor and Sawpitts had differing arithmetic and geometric mean microbial counts for HPC, total coliforms and *E. coli*, thus resulting in different categories of risk of microbial infection in users being associated with each mean type (*i.e.* arithmetic and geometric mean) (Table 10).

Arithmetic mean counts showed that occupants from ground tank-supplied households, in Sawpitts and Cato Manor, in all three sample demographic groups, were at a negligible risk of microbial infection as a result of the HPC counts and at a potential risk of microbial infection as a result of total coliform and *E. coli* counts. Geometric mean microbial counts of HPC and total coliforms in ground tank-supplied water placed users, in all three demographic groups, at a potential risk and substantial risk of microbial infection respectively, with the exception of water sampled from ground tank-supplied homes in Sawpitts which included children aged >5-18 years which had total coliform counts that posed a potential risk of microbial infection to users. Geometric mean microbial counts in water sampled from ground tank-supplied households in Cato Manor had *E. coli* counts that posed a substantial risk of microbial infection to users in all age groups except the >18 year group, in which *E. coli* posed a potential risk of infection to users. (Table 10). According to arithmetic mean microbial counts, community tanker-supplied drinking water posed a substantial risk of microbial infection to users, in all three demographic groups, in one parameter (HPC) and a potential risk of microbial infection to users in two parameters (total coliforms and *E. coli*). This differed slightly for geometric mean microbial counts, in which case, community tanker-supplied drinking water posed a substantial risk of microbial infection to users, in all demographic groups, in all three microbial parameters (HPC, total coliforms and *E. coli*) (Table 10).

People from households supplied drinking water by community tankers in any of the three demographic groups were at the highest risk of microbial infection since the microbial counts in water at point-of-use exceeded recommended levels in DWAF and WHO guidelines to the greatest extent (Table 1). Microbial counts in point-of-use water supplied by ground tanks in Cato Manor, standpipes and community tankers had the highest *E. coli* and total coliform counts in households including children aged 0-5 or >5-18 years and fell in the category of potential risk, according to the arithmetic mean and the category of substantial risk according to the geometric mean, according to DWAF and WHO guidelines (Table 1) for safe drinking water. Therefore faecal contamination of water is more prominent in households including children than households comprising adults only (Table 10). Where the geometric mean differed from the arithmetic mean, the risk of microbial infection associated with geometric mean values were always higher than the risk of microbial infection associated with arithmetic mean values. This is however an expected occurrence, since the geometric mean measures central tendency whilst the arithmetic mean measures an average.

Table 10 Arithmetic mean (AM) and geometric mean (GM) microbial counts for point of-use water discriminated by age distribution (heterotrophic plate counts (HPC) in cfu/mL, total coliforms and *E. coli* in cfu/100mL).

Sample group	Age		HPC (cfu/ml)	Risk	Total Coliforms (cfu/ 100mL)	Risk	E. Coli (cfu/100mL)	Risk
Standpipes	0-5 yrs	AM	**200**		**40**		**1**	
		n[d]=	160	PR[b]	160	PR	160	PR
		GM	**560**		**410**		**97**	
		n=	160	PR	86	SR[c]	59	SR
	5-18 yrs	AM	**316**		**46**		**3**	
		n=	160	PR	160	PR	160	PR
		GM	**640**		**470**		**160**	
		n=	168	PR	48	SR	62	SR
	>18 yrs	AM	**398**		**45**		**2**	
		n=	160	PR	160	PR	160	PR
		GM	**720**		**430**		**13**	
		n=	159	PR	41	SR	25	SR
Ground tanks (Cato Manor)	0-5 yrs	AM	**46**		**10**		**3**	
		n=	89	NR[a]	89	PR	89	PR
		GM	**340**		**310**		**340**	
		n=	87	PR	74	SR	64	SR
	5-18 yrs	AM	**40**		**9**		**2**	
		n=	89	NR	89	PR	89	PR
		GM	**380**		**290**		**320**	
		n=	85	PR	54	SR	51	SR
	>18 yrs	AM	**50**		**6**		**1**	
		n=	89	NR	89	PR	89	PR
		GM	**350**		**250**		**2**	
		n=	78	PR	42	SR	14	PR
Ground tanks (Cato Manor)	0-5 yrs	AM	**40**		**32**		**1**	
		n=	93	NR	93	PR	93	PR
		GM	**170**		**120**		**1**	
		n=	92	PR	41	SR	3	PR
Ground tanks (Sawpits)	5-18 yrs	AM	**25**		**20**		**2**	
		n=	93	NR	93	PR	93	PR
		GM	**160**		**99**		**7**	
		n=	89	PR	32	PR	58	PR
	>18 yrs	AM	**20**		**20**		**1**	
		n=	93	NR	93	PR	93	PR
		GM	**160**		**110**		**5**	
		n=	78	PR	43	SR	12	PR
Community tankers	0-5 yrs	AM	**3 981**		**50**		**4**	
		n=	160	SR	160	PR	160	PR
		GM	**195 000**		**230**		**110**	
		n=	160	SR	64	SR	49	SR
	5-18 yrs	AM	**5 011**		**61**		**2**	
		n=	160	SR	160	PR	160	PR
		GM	**100 000**		**250**		**77**	
		n=	154	SR	49	SR	32	SR

Sample group	**Age**		**HPC (cfu/ml)**	**Risk**	**Total Coliforms (cfu/ 100mL)**	**Risk**	**E. Coli (cfu/100mL)**	**Risk**
Community tankers	**5-18 yrs**	**AM**	**5 011**		**61**		**2**	
		n=	160	**SR**	160	**PR**	160	**PR**
		GM	**100 000**		**250**		**77**	
		n=	154	**SR**	49	**SR**	32	**SR**
	>18 yrs	**AM**	**3 981**		**60**		**3**	
		n=	160	**SR**	160	**PR**	160	**PR**
		GM	**48 000**		**240**		**93**	
		n=	123	**SR**	26	**SR**	12	**SR**

[a]NR-negligible risk.
[b]PR- potential risk.
[c]SR- substantial risk).
[d]n represents the number of samples used to derive mean values.

The pH, turbidity, conductivity, residual chlorine and total chlorine levels in water sampled from standpipe, ground tank and community tanker-supplied households including children aged 0-5 years, children aged >5-18 years and households comprising adults only (>18 years), are given below in Table 11. The standard deviations and means for all physico-chemical parameters are given in Table 11.

The pH of water for all demographic groups supplied by any of the three delivery systems was within the recommended levels according to WHO and DWAF guidelines (guidelines given in Chapter 2, Table 2). Point-of-use water from all delivery systems, except community tankers, had turbidity values which fell within the guideline values of one to five NTU. Community tanker water in all three demographic groups had turbidity values which exceeded guideline values, with households comprising adults only having the highest turbidity values.

Conductivity values for all demographic groups supplied by any of the delivery systems were all within the recommended guideline values of < 100 mS/m. Total and residual chlorine levels were within guideline values for standpipe and Cato Manor ground tank-supplied households for all demographic groups, however ground tank-supplied water in Sawpitts and Community tanker-supplied water had residual chlorine levels below recommended guideline levels for all demographic groups (Table 11).

Table 11 Average pH, residual Cl (mg/L), free Cl (mg/L), turbidity (NTU) and conductivity (mS/m) for all point-of-use water samples from households including children aged 0-5 years, children aged 5-18 years and households comprising occupants >18 years (adults).

Delivery systems	Demographics	pH	Residual Cl (mg/L)	Total Cl (mg/L)	Turbidity (NTU)	Conductivity (mS/m)
Standpipes	**0-5 years**	**7.9**	**0.2**	**0.4**	**1.4**	**15.5**
	n =	160	160	160	160	160
	SD	0.16	0.15	0.21	3.3	2.8
	>5-18 years	**7.9**	**0.3**	**0.4**	**1.1**	**15.4**
	n =	160	160	160	160	160
	SD	0.11	0.15	0.20	1.18	2.8
	>18 years (Adults)	**7.9**	**0.2**	**0.3**	**0.8**	**15.3**
	n =	160	160	160	160	160
	SD	0.09	0.13	0.19	0.34	2.6
Ground tanks (Cato Manor)	**0-5 years**	**8**	**0.4**	**0.6**	**0.6**	**14.9**
	n =	89	89	89	89	89
	SD	0.15	0.18	0.20	0.43	1.7
	>5-18 years	**8**	**0.4**	**0.5**	**0.6**	**14.9**
	n =	89	89	89	89	89
	SD	0.15	0.17	0.19	0.38	1.6
	>18 years (Adults)	**8**	**0.4**	**0.6**	**0.7**	**14.9**
	n =	89	89	89	89	89
	SD	0.11	0.18	0.20	0.83	2.04
Ground tanks (Sawpitts)	**0-5 years**	**8.1**	**0.1**	**0.1**	**0.5**	**12.5**
	n =	93	93	93	93	93
	SD	0.37	0.7	0.9	0.24	0.84
	>5-18 years	**8.1**	**0.1**	**0.1**	**0.6**	**12.2**
	n =	93	93	93	93	93
	SD	0.35	0.07	0.08	1.43	1.56
	>18 years (Adults)	**8.1**	**0.1**	**0.1**	**0.5**	**12.6**
	n =	93	93	93	93	93
	SD	0.34	0.07	0.08	1.43	1.56
Community tankers	**0-5 years**	**8**	**0.1**	**0.1**	**7**	**6.9**
	n =	160	160	160	160	160
	SD	0.17	0.16	0.27	0.54	6.24
	>5-18 years	**8**	**0.1**	**0.1**	**7**	**7**
	n =	160	160	160	160	160
	SD	0.14	0.17	0.70	5.4	6.2
	>18 years (Adults)	**8**	**0**	**0.1**	**8.1**	**5.5**
	n =	160	160	160	160	160
	SD	0.13	0.80	0.10	5.3	6.1

[a] n represents the sample size.
[b] SD represents the standard deviation.

4.4. Links between microbial water quality, health outcomes, socio-economic status, household demographics and hygiene practices.

In order to establish if links existed between microbial drinking water quality, incidences of health outcomes and socio-economic status, data from an epidemiological study by Lutchminarayan, 2007 was merged with microbial data from the current study. These two data sets were statistically analysed to identify relationships between the parameters measured in that study and water quality as measured in the present study. Household demographics and hygiene practices of household members were also included in the analysis. It is acknowledged that a small sample size was used, but comparisons were made with respect to health outcomes despite this limitation because guideline values were phrased in terms of potential health impacts (microbial infection) and this comparison allowed contributing factors to health outcomes to be interrogated. However, the limitations posed by small sample size are acknowledged.

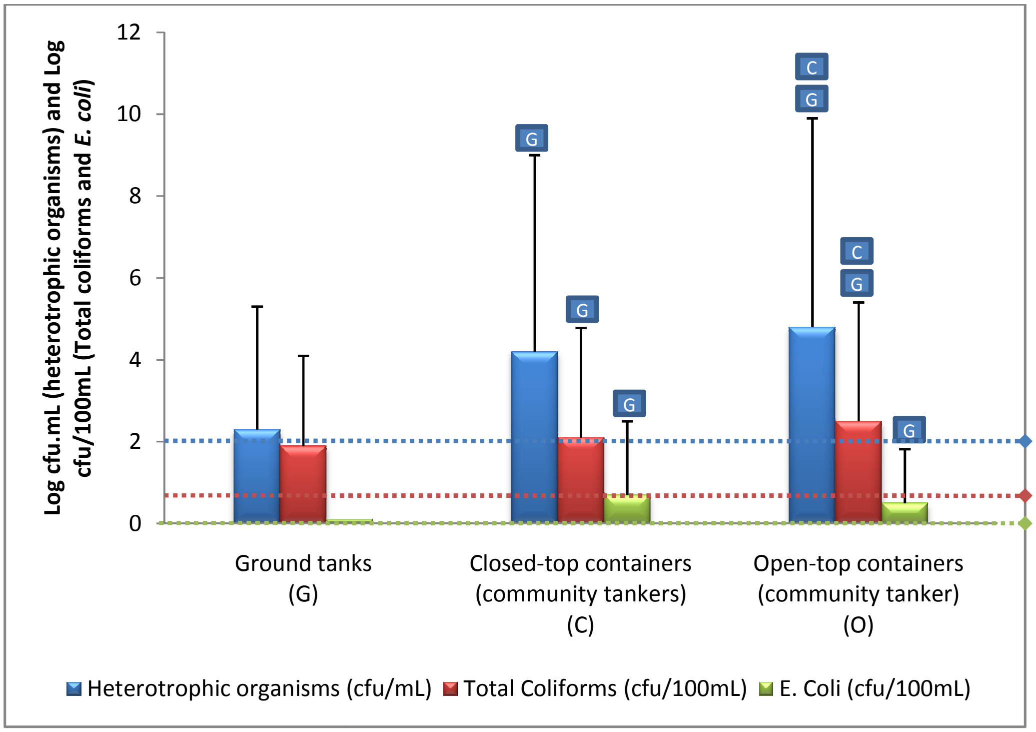
4.4.1. The relationship between point-of-use microbial drinking water quality, age distribution in households and health outcomes.

Microbial counts in point-of-use water, supplied by community tankers, stored in open-top and closed-top containers and microbial counts of point-of-use water sampled from ground tanks, are given in Figure 14. Data for standpipe-supplied households and Cato Manor community tanker-supplied households is not included in this section since the epidemiology study, by Lutchminarayan (2007), only made use of two areas used in the present study, namely Sawpitts (supplied water by ground tanks) and Mtamuntengayo (supplied water by community tankers).

There were significantly fewer *E. coli*, total coliforms and heterotrophic organisms in water from ground tanks when compared with that from closed-top and open-top storage containers supplied by community tankers (p=0.0005 for all) (Figure 14).

There were significantly more coliforms and heterotrophic organisms in water from open-top containers when compared with that from both closed-top containers (p=0.0005 and p=0.001, respectively) and ground tanks (p=0.0005 for both) (Figure 14). Even though community tanker source water for open-top containers was of a poor quality the deterioration of microbial water quality at the point-of-use (open-top container) was significant in comparison to source water quality (Figure 12).

DWAF guideline values (Table 1), as marked on Figure 14, indicate that water from ground tanks, open-top containers and closed-top containers all have heterotrophic and total coliform counts which exceed the maximum allowed levels as per DWAF guidelines and hence pose a substantial risk of microbial infection to users. The upper limit of risk of the 95th percentile, for heterotrophic organisms and total coliforms, places water from all three storage systems (ground tanks, open-top containers and closed-top containers) in the category of posing a substantial risk of infection to users. Community tanker-supplied water from open-top and closed-top containers also posed a substantial risk of microbial infection to users with regard to the upper limit of risk presented by the 95th percentile for *E. coli*. Blue boxes on the graph indicate where microbial counts are significantly higher.

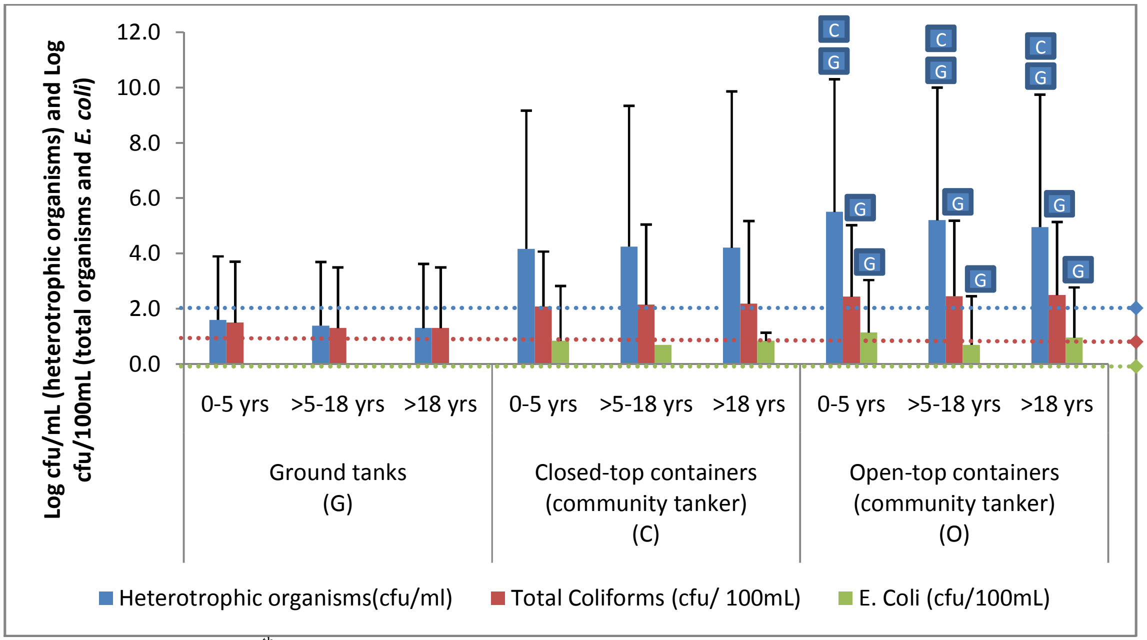


*Error bars represent the 95th percentile. Horizontal lines represent maximum values of heterotrophic organisms (blue), total coliforms (red) and *E. coli* (green) counts allowed in drinking water rendered safe for human consumption. Blue boxes represent significant differences in microbial counts.

Figure 14 Log arithmetic mean microbial counts at point-of-use for households using ground tanks as a water delivery and storage system and for community tanker-supplied households using closed-top and open-top containers as water storage systems.

The relationship between age distribution in households (households including children aged 0-5 years, households including children aged >5-18 years and households comprising adults only) and microbial quality of drinking water at the point-of-use is given below in Figure 15.

The highest heterotrophic organism and *E. coil* counts were observed in water from households including children aged 0-5 years and which used open-top containers for water storage. Heterotrophic organism counts were significantly higher in this group in comparison to all closed-top container and ground tank-supplied household groups. Households comprising adults only and which used open-top containers for water storage displayed the highest total coliform counts, but not significantly so (Figure 15). The upper risk limit of the 95th percentile indicates that heterotrophic organisms and total coliforms are present in high enough quantities in all three storage systems (ground tanks, open-top and closed-top containers) to pose substantial risk of microbial infection to users. For ground tank-supplied households *E. coli* levels were very low and according to upper limit of risk presented by the 95th percentile, no risk of microbial infection was posed to users. Blue boxes on the graph indicate where microbial counts are significantly higher.



*Error bars represent the 95th percentile. Horizontal lines represent maximum values of heterotrophic organisms (blue), total coliforms (red) and *E. coli* (green) counts allowed in drinking water rendered safe for human consumption. Blue boxes represent significant differences in microbial counts.

Figure 15 Arithmetic mean microbial counts for households including children aged 0-5 years or children aged >5-18 years and households comprising adults only (>18 yrs), which use ground tanks, open-top or closed-top containers for domestic water storage and use.

Water quality from open-top and closed-top containers, supplied by community tankers, to households comprising adults only and households including children aged 0-5 and >5-18 years (Table 12), was compared to the South African water quality guidelines for drinking water (Table 1) (DWAF, 1996).

Arithmetic mean microbial counts for ground tank water placed users at a negligible risk of microbial infection in one parameter (HPC) and at a potential risk of obtaining microbial infection in two parameters (total coliforms and *E. coli*). The geometric means however showed that water from ground tanks had HPC and *E. coli* counts which posed a potential risk of causing microbial infection to users. Geometric mean counts of total coliforms showed that water from households including children aged 0-5 years and households comprising adults only posed a substantial risk of microbial infection to users (Table 12).

All arithmetic and geometric mean counts of HPC and total coliforms in community tanker-supplied water stored in open-top or closed-top containers posed a substantial risk of infection to users. Arithmetic and geometric mean microbial counts of *E. coli* from water stored in open-top containers, sampled from households including children aged 0-5 years posed a substantial risk of microbial infection to users. Water samples from households with children aged >5-18 years and households with adults only had *E. coli* counts which posed a potential risk of infection to users (Table 12). Therefore water from all three point-of use samples (open-top and closed-top storage containers and ground tanks) did not meet DWAF guidelines as being safe for drinking purposes.

The level of risk presented by the 95th percentile differed from the level of risk presented by the geometric and arithmetic mean in the following instances:

- 95th percentile values of heterotrophic bacteria and total coliforms placed ground tank water in the category of causing substantial risk of microbial infection to users. Arithmetic means placed the same water at a negligible risk of microbial infection for heterotrophic organisms and at a potential risk of causing microbial infection in users for total coliforms. The geometric mean microbial counts of heterotrophic organisms placed ground tank water in the category of causing potential risk of infection to users.

- The upper limit of risk presented by the 95th percentile for *E. coli* in water from open-top containers, supplied by community tankers, placed this water in the category of causing a substantial risk of infection to users in households including children aged >5-18 years and in households comprising adults only. This differed for the geometric and arithmetic mean which rendered this water as posing a potential risk of infection to users.

The arithmetic mean, geometric mean and upper limit of the 95th percentile for heterotrophic organisms and total coliforms provided the same result with regard to the level of risk associated with water from open-top and closed-top containers, which were sampled from households comprising any of the three age groups studied. The finding here showed that all three statistical measures rendered water as posing a substantial risk of microbial infection to users (Figure 15, Table 12).

Table 12 Arithmetic mean (AM) and geometric mean (GM) microbial counts from ground tank and community tanker-supplied point of-use water (water in open-top and closed-top containers) distinguished between by age distribution (heterotrophic plate counts (HPC) in cfu/mL, total coliforms and *E. coli* in cfu/100mL).

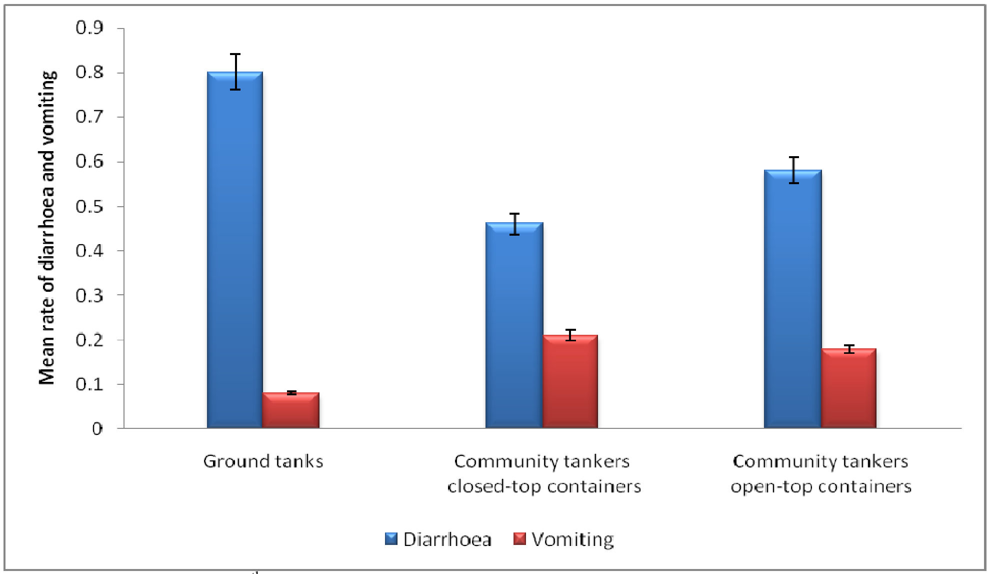
Point-of-use	Age		HPC (cfu/mL)	Risk	Total coliforms (cfu/100mL)	Risk	*E. coli* (cfu/100mL)	Risk
Ground tanks	0-5 yrs	**AM**	**40**	**NR[a]**	**32**	**PR**	**1**	**PR**
		n[d]=	93		93		93	
		GM	**170**	**PR[b]**	**120**	**SR[c]**	**1**	**PR**
		n=	92		41		3	
	>5-18 yrs	**AM**	**25**	**NR**	**20**	**PR**	**2**	**PR**
		n=	93		93		93	
		GM	**160**	**PR**	**99**	**PR**	**7**	**PR**
		n=	89		32		58	
	> 18 yrs	**AM**	**20**	**NR**	**20**	**PR**	**1**	**PR**
		n=	93		93		93	
		GM	**160**	**PR**	**110**	**SR**	**5**	**PR**
		n=	78		43		12	
Closed-top containers (Community tankers)	0-5 yrs	**AM**	**14 858**	**SR**	**122**	**SR**	**7**	**PR**
		n=	80		80		80	
		GM	**15 683**	**SR**	**138**	**SR**	**9**	**PR**
		n=	80		45		42	
	>5-18 yrs	**AM**	**17 758**	**SR**	**142**	**SR**	**5**	**PR**
		n=	80		80		80	
		GM	**18 598**	**SR**	**173**	**SR**	**8**	**PR**
		n=	78		32		12	

Point-of-use	Age		HPC (cfu/mL)	Risk	Total coliforms (cfu/100mL)	Risk	*E. coli* (cfu/100mL)	Risk
Closed-top containers (Community tankers)	> 18 yrs	**AM**	**16 235**	**SR**	**153**	**SR**	**7**	**PR**
		n=	80		80		80	
		GM	**16 785**	**SR**	**159**	**SR**	**8**	**PR**
		n=	74		28		9	
Open-top containers (Community tankers)	0-5 yrs	**AM**	**318 025**	**SR**	**271**	**SR**	**14**	**SR**
		n=	80		80		80	
		GM	**327 654**	**SR**	**302**	**SR**	**16**	**SR**
		n=	79		23		43	
	>5-18 yrs	**AM**	**161 104**	**SR**	**287**	**SR**	**5**	**PR**
		n=	80		80		80	
		GM	**176 549**	**SR**	**305**	**SR**	**7**	**PR**
		n=	77		22		15	
	> 18 yrs	**AM**	**90 125**	**SR**	**314**	**SR**	**9**	**PR**
		n=	80		80		80	
		GM	**102 692**	**SR**	**421**	**SR**	**10**	**PR**
		n=	72		16		14	

[a] NR-negligible risk.
[b] PR- potential risk.
[c] SR- substantial risk).
[d] n represents the number of samples used to derive mean values.

The relationship between water quality at the point-of-use (storage containers and ground tanks) and health outcomes (diarrhoea and vomiting) is presented in Figure 16. The rate of diarrhoea was highest among members of households using ground tanks at the point-of-use, followed by members of households using water from open-top containers and then water from closed-top containers, where rate is used as defined in the Methods chapter (Figure 16). However, these differences were not significant. The rate of diarrhoea showed an opposite trend to water quality and to risks according to guidelines. This therefore suggests that factors other than the microbial quality of water contribute to the rate of diarrhoea.

Rate of vomiting was lower in households using ground tanks for water storage than in those using open-top or closed-top storage containers. Again, this was not significant (Figure 16).

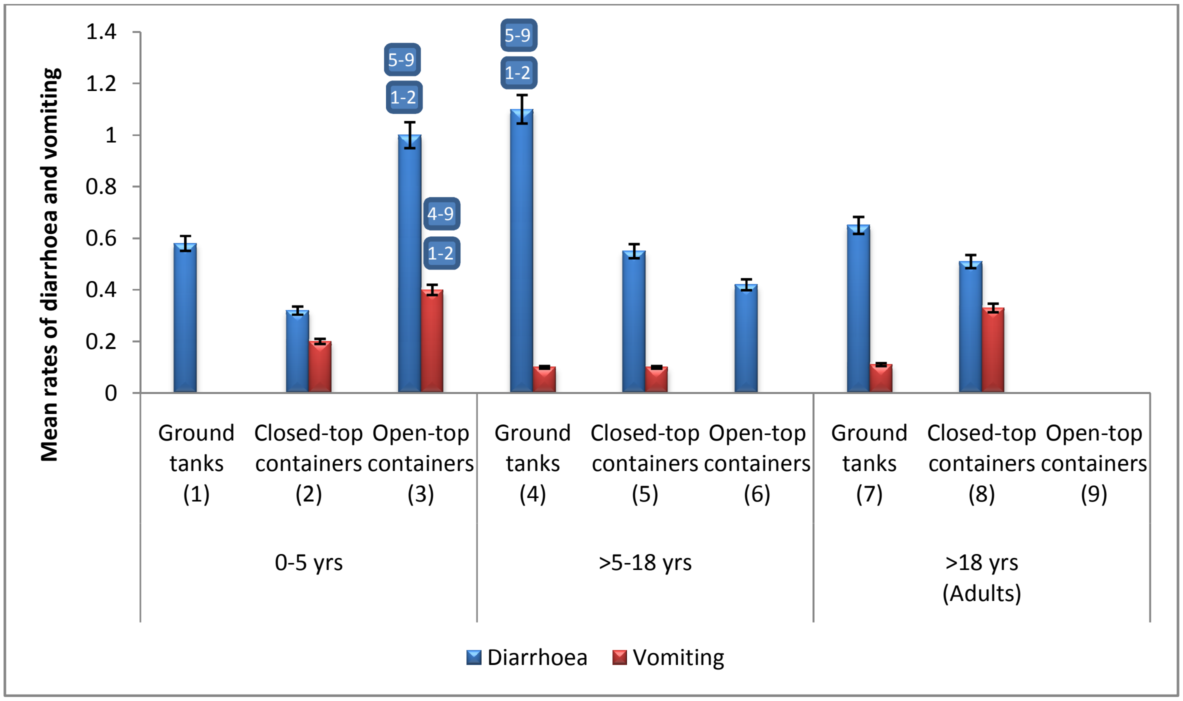


*Error bars represent the 95th percentile.

Figure 16 Mean rates of diarrhoea and vomiting in households using ground tanks, open-top or closed-top containers for water storage and supply.

The relationship between water quality at the point-of-use (storage containers and ground tanks), health outcomes (diarrhoea and vomiting) and age distribution in households was also investigated (Figure 17).

Figure 15 shows that generally, the microbial quality of drinking water in households including children aged 0-5 and >5-18 years of age was worse than in households comprising adults only. Households using ground tanks and which had a demographic distribution of children in the 0-5 year range had water with the lowest *E. coli* and total coliform counts (Figure 15). Members of these households presented with the highest rate of vomiting, this rate was significantly higher than all other demographic groups receiving drinking water from ground tanks, open-top or closed-top containers ($p<0.001$) (Figure 17). Even though the *E. coli* counts in ground tank water was less than that in water from open-top or closed-top storage containers (Figure 15), the highest rate of diarrhoea still occurred amongst members aged >5-18 years in households using ground tanks for water storage, this rate was significantly higher than all other demographic groups using ground tanks, open-top or closed-top storage containers as point-of-use water supplies ($p<0.001$) (Figure 15 and Figure 17). This therefore suggests, again, that the rate of health outcomes is influenced by factors other than the microbial quality of drinking water. A possible explanation for the high rate of diarrhoea in this group could be the fact that this group comprises children of school-going age and hence infections may be picked up at school. On a qualitative basis, the rate of all health outcomes was significantly higher in households with children aged 0-5 and >5-18 years using open-top containers or ground tanks, respectively, as the point-of-use, in comparison to all other demographic groups using ground tanks, open-top or closed-top containers as a point-of-use water supply (Figure 17).



*Error bars represents the 95th percentile. Blue boxes represent significant differences in mean rates of diarrhoea and vomiting amongst the various age groups analysed.

Figure 17 Mean rates of diarrhoea and vomiting in households using ground tanks, open-top or closed-top containers for domestic water storage at the point-of-use. Rate of diarrhoea and vomiting is also distinguished between by age distributions.

Overall no direct relationships were found between water quality and health with regard to vomiting and diarrhoea amongst all three age groups analysed.

4.4.2. Relationship between socio-economic factors and health

Although intervention areas (areas provided with UD toilets and ground tanks) were provided with UD toilets, not everyone used them. Some household members still preferred to practice open defaecation. Table 13 shows that, for those households where not everyone used the UD toilet, there was a higher rate of diarrhoea (p=0.036). If the outside toilet was used but not clean, significantly higher rates of diarrhoea were observed among toilet users (p=0.028). This indicates that the use of UD toilets and practice of good hygiene are closely related to the aversion of cases of diarrhoea.