

Chapter 5

GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

Almost 1.1 billion people in the world do not have access to improved water supplies and many of these people are without access to “safe drinking water” supplies (WHO, 2005). In addition, burden of disease data from the World Health Organisation, suggests that 1.8 million deaths and 61.9 million disability-adjusted life years worldwide are due to unsafe water, sanitation and hygiene (WHO, 2004). In developing countries, 98% of deaths are due to unsafe water, sanitation and hygiene of which 90% of these deaths are children (WHO, 2004).

The Millennium Development Goal of the United Nations aimed to halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation (UN, 2000). Unfortunately the definition of “safe drinking water” is not clearly understood and is interpreted differently in various countries. Even if a household is supplied by a standpipe within 200 m from the dwelling, the water the tap provides may still be contaminated because of the poor microbiological quality of the source (Chapter 2). In addition, the potential for water contamination during transport from the source to the dwelling and subsequent storage makes the challenge of providing “safe drinking water” even greater. Therefore point-of-use treatment systems is seen as providing “safe drinking water” to communities, households and individuals who are in desperate need for clean water (Sobsey, 2002).

This study was the first of its kind to be conducted in the rural communities of the Vhembe region of the Limpopo Province of South Africa. The results obtained from this study may be used to investigate the water quality of other rural communities on the African continent with similar environmental conditions. The microbiological quality of water sources in rural communities were assessed to determine the microbiological deterioration of household stored water at the point-of-use and evaluated the use of a

simple user friendly, affordable intervention system consisting of the CDC safe storage container together with a sodium hypochlorite solution was evaluated. The CDC safe storage container with or without a sodium hypochlorite solution was further assessed in a laboratory based study to determine the survival of indicator microorganisms and pathogenic waterborne microorganisms over a period of 5 days. In addition, genotyping of male specific F-RNA bacteriophage subgroups were used to determine the origin of animal or human faecal contamination inside the household stored water supplies. All three objectives as outlined in Chapter 1 have been achieved and several important findings from the results will be highlighted in this chapter.

5.2 AN INTERVENTION STRATEGY TO IMPROVE THE DRINKING WATER QUALITY IN RURAL HOUSEHOLDS

Point-of-use water treatment systems should be safe, affordable, free of bacteria and effective (Sobsey, 2002). The results obtained in this study have showed that the CDC protocol (chlorine based water treatment combined with safe storage and education) did fulfill all these criteria for rural households in South Africa. Therefore, this study contributes to the existing literature on the use of the Safe Water System developed by the CDC.

Microbiological assessment of the water from the primary water sources (river and communal tap sources) used by the two study populations, indicated that these sources were already faecally contaminated and had unacceptable high counts for heterotrophic bacteria, total coliform bacteria, faecal coliform bacteria, faecal enterococci and *Clostridium perfringens* according to the recommended South African guidelines for potable water (SABS, 2001). No statistical differences in the Heterotrophic bacterial counts ($P=0.272$) was seen between the river and tap water sources. However, statistical differences were seen in the total coliform bacterial counts ($P=0.004$), faecal coliform bacterial counts ($P= 0.004$), *E. coli* counts ($P=0.010$), faecal enterococci bacterial counts ($P=0.001$) and *C. perfringens* bacterial counts ($P=0.001$) between the river and tap water sources. Implications are that contamination of these water sources could mostly be due to human faecal pollution. A clear difference between improved (communal tap) and unimproved (river) sources (Gundry *et al.*, 2004) could be seen in

the microbial counts of these two sources during this study. The unimproved water source (river) had higher counts of total coliform bacteria, faecal coliform bacteria and faecal enterococci bacteria. However, the results indicated that the definition of what constitutes an improved water source should be revised. In this study the communal tap water sources had indicator bacterial counts all exceeding the South African water quality guideline limits for safe drinking water. The results of this study are indicating that although communities are provided with communal taps, the water is not necessarily microbiologically acceptable or safe to drink as the general perception is.

Water samples from the traditional and CDC safe storage containers in the households using the placebo solution, indicated that water further deteriorated after collection and during storage at the point-of-use. Various reasons have been proposed for the deterioration of water quality between the source and point-of-use of which the two leading factors include the hygiene condition of the storage container and the environment in which these storage containers are stored (Jagals *et al.*, 1999; Gundry *et al.*, 2004; Jagals *et al.*, 2003; Trevett *et al.*, 2005; Maraj *et al.*, 2006). These studies have showed that uncovered containers are exposed to environmental conditions such as dust and dirt, children and animals which could be potential sources of faecal contamination (Jensen *et al.*, 2002; Rosas *et al.*, 2006). The baseline characteristics of the households in the two villages implied that various factors could have played a role in the increase of the water at the point-of use in both the traditional and CDC safe storage containers without the addition of the 1% or 3.5% sodium hypochlorite solutions. These factors included dust and dirt (Rosas *et al.*, 2006), biofilm growth and/or bacterial regrowth (Vanderslice and Briscoe, 1993; Momba and Notshe, 2003), storage and handling conditions of the water storage containers as well as hygiene and sanitation practices (Jagals *et al.*, 1999).

The results of the efficiency of the intervention in the households from the two villages clearly indicated that no statistical significant difference in the counts of heterotrophic bacteria could be seen between the water source and the household storage containers in both study villages. However, the results clearly showed that in households using tap water, a statistical significant difference ($P < 0.05$) could be seen between the water source and the household storage containers in the counts for total coliform bacteria,

faecal coliform bacteria, faecal enterococci and *C. perfringens*. However, no statistical differences ($P > 0.05$) were seen in the *E. coli* counts in households using tap water and their household stored water.

Finding *E. coli* in water primarily means such water is faecally polluted. From a water-suitability perspective, one would then manage this by discouraging ingestion of such waters not only because of faecal pollution, but also because of the potential presence of other bacterial pathogens *E. coli* are reported to indicate. Finding *E. coli* in water is practically the same as to finding other pathogens in there as well. This is the fundamental reason why most water quality guidelines use *E. coli* bacteria as the common indicator of microbiological quality of water that people use. The use of *E. coli* as an indicator is firmly entrenched in many water quality guidelines as well as in institutional approaches towards managing water quality. However, current *E. coli* tests for water are designed to test for the indicator value based on the fact that most strains of *E. coli* are actually harmless commensals from the gut of warm-blooded animals and humans. It is reported that pathogenic *E. coli* are not cultured in the faecal flora of health individuals. Certain strains of *E. coli* do in themselves actually become pathogenic depending on circumstances between excretion (into faecally polluted water) and infection of a naïve host. This has led to a growing realisation that these strains of *E. coli* may even be the dominant bacterial pathogen species in faecally polluted water. This implies that technologies that were originally intended for simply indicating the potential presence of bacterial pathogens in water can, to a large extent, also confirm the presence of at least a substantial portion of bacterial pathogens that could commonly occur in water contaminated with faecal material. However, we do not know which *E. coli* strains are reflected in our indicator tests and whether they are pathogenic. If we develop an index of which *E. coli* strains dominate in a given water environment, we could anticipate the strains people would ingest should they use the water untreated. However, these households did not have any diarrhoea incidence during the intervention study. These are signs that the *E. coli* in that environment were indeed of the harmless strains and that the pathogens these were supposed to indicate were absent. Or it shows human immune systems that can deal with infection. To complicate matters further, we found that in other households, stored water contains lower *E. coli* numbers but diarrhoea is prevalent and even persistent. This could well be from the other carrier

media such as food, but it still shows that there are sub-populations in areas that do not cope immunologically. Or it might imply that the *E. coli* strains in that area are pathogenic. We have no way of telling. This implies a weakness in the classical *E. coli* indicator approach. The presumptive pathogens (indicated by detection *E. coli*) may potentially cause diarrhoea when ingested, but the actual effect (predicted by guideline values) may then not turn out as predicted in the consumer population. Using guidelines based on microbiological water quality alone is following a no-adverse-effect-level approach. In other words we should begin to observe certain health effects in populations if the water that they access (and ingest) for their daily needs, contain numbers of the indicator organism (*E. coli*) above a certain level.

Likewise the results from the intervention trial showed that in households using river water, a statistical significant difference ($P < 0.05$) could be seen between the water source and the household storage containers in the counts for total coliform bacteria, faecal coliform bacteria and *E. coli* bacteria. However, no statistical differences ($P > 0.05$) were seen in the faecal enterococci and *C. perfringens* counts in households using river water and their household stored water, which suggested that resistant spores and vegetative cells were present in the river water.

Furthermore, the results from this study have indicated no statistical differences ($P > 0.05$) between the traditional and the CDC safe storage containers using the placebo solution in both study populations with regards to the prevalence of indicator microorganisms. This indicated that the CDC safe container as a single intervention without a sodium hypochlorite solution was not effective in the prevention of secondary contamination and therefore did not improve the microbiological quality of the stored drinking water. This was in agreement with an earlier study conducted by Quick and co-workers (1996) who indicated that the CDC safe storage container without the sodium hypochlorite intervention is not effective in reducing the risk associated with waterborne diseases. Therefore, other pathways of faecal contamination of the domestic water at the point-of-use must be research in the households. The role of zoonoses and biofilms inside the storage containers needs to be investigated further.

Consequently, this study has showed that treatment of water at the point-of-use with a sodium hypochlorite solution (1% or 3.5%) was 100% effective and people complied with the use of the sodium hypochlorite solutions when provided. The effectivity of the 1% and 3.5% sodium hypochlorite solutions are in agreement with the laboratory studies concerning the survival of total and faecal coliform bacteria, faecal enterococci bacteria, *E. coli* bacteria, *C. perfringens* bacteria and somatic bacteriophages in both the unimproved (river) and improved (groundwater/communal tap) water samples.

It was also found during this study that people did not generally wanted to wait 2 h or longer after the addition of a chlorine treatment before drinking or using the water. The households usually collected enough water for their daily household needs and then used the water immediately for the intended purpose. Therefore, educational interventions are needed to give the communities knowledge on behavior changes and health benefits.

The DOH in South Africa is promoting the use of the 3.5% sodium hypochlorite solution during disease outbreaks. Results of this study indicated that free chlorine residual of 0.8 mg.l^{-1} as specified by the WHO (2004) was only obtained after 24 h for the 3.5% sodium hypochlorite solution which is recommended by the DOH in South Africa. The questions that needs to be asked concerning this aspect: *Is it rather a case of overkill and not effective assessment of the health risks of the high sodium hypochlorite solution?* This study has, however, showed that home treatment of drinking water with a sodium hypochlorite solution is a viable option to provide “safe drinking water” in rural communities and households in South Africa without adequate water and sanitation infrastructures.

In this study diarrhoea was not used as a health outcome because the VhaVenda and Shangaan communities in the Vhembe region of the Limpopo Province, South Africa, do not consider or perceive diarrhoea as a health threat, except for serious diseases such as cholera. In fact, diarrhoea was seen as necessary to clean the body and was even induced by taking traditional medicine. The main concern with regards to these rural communities was the lack of knowledge on the effect of diarrhoea on the most vulnerable group namely young children (Ashbolt, 2004). Inquiries into the prevalence

of diarrhoea in the two communities by looking at the Primary Health Care (PHC) clinic's data on diarrhoea incidences, indicated that diarrhoea was not a serious problem in these communities. Basically there could be two conclusions drawn from this: (1) Diarrhoea is underreported because mothers only take the child to the PHC clinic when the child is dehydrated. In general the mother treat the child at home with indigenous medicines (personal communication with several community members and PHC clinic staff) and (2) Adults and children has a natural immunity towards the microorganisms in their drinking water due to exposure at an early age. These findings could have serious implications for future intervention studies where the risk of diarrhoeal diseases will be used as an outcome to determine the effectiveness of the water treatment system. Cultural believes and living conditions must be taken into consideration before implementing intervention systems within a community.

Although many studies have reported on the effectiveness of household interventions, data on the sustainability of these interventions are scarce and warrants further investigation (Wilson and Chandler, 1993; Conroy *et al.*, 1999). This study has investigated the sustainability of the intervention at 6 and 12 months intervals respectively after the initial intervention trial. It was found that households in village 1 using the improved water source (communal tap water), complied with the intervention protocol even 12 months after the original trial. These households used the free supply of 1% and 3.5% sodium hypochlorite solutions provided. However, households in village 2 using the unimproved water source (river water), did not comply with the intervention protocol even though they were also supplied with free bottles of 1% and 3.5% sodium hypochlorite solutions. The microbiological quality of the stored household water of households in this study indicated an increases health risk. Generally, the only difference between the two study villages, apart from the primary water source, was the fact that the chief in village 1 took a keen interest in the study and supported the idea of providing "safe drinking water" to his people. The chief was an educated person and the head of the secondary school in the community. The results from this study showed that households from village 1 were motivated and their behavior around water issues has changed. However, the chief from village 2, was not interested in the study because according to him it was a woman's issue to look at the household drinking water.

Of particular concern is the rising population in South Africa that is vulnerable to infection such as people infected with HIV/AIDS, young children and old people with declining immune systems. Safe drinking water also depends on hygiene practices which keep faecal matter from reaching stored domestic water supplies. It is important that facilities for the safe disposal of feces and hand washing close to the toilet are available (Trevett *et al.*, 2005). Waterborne pathogens could also be transmitted within a household by ingestion of contaminated food and beverages, person-to-person contact and direct/indirect contact with faeces (Trevett *et al.*, 2005). A study by Trevett and co-workers (2005) has indicated that the type of storage container and hand contact with drinking water was associated with increased risk of disease in the household. In this study the overall risk estimate of disease with regards to *E. coli* counts was 0.58 (95% CI 0.349 – 0.950) for people who washed their hands before food preparation. This highlights the need of proper education of rural communities on the benefits of hand washing. The study by Trevett and co-workers (2005) has also indicated that cultural beliefs, sanitary conditions and poverty affects the pathogen load in the household. It is understandable that people who have to walk far to collect water for household purposes, would be careful not to waste water unnecessary. In such cases, regular washing of hands are not a high priority in the household.

The long term plan of the South African government is to improve accessibility of all households to municipal treated standpipe water in the household or at least inside the dwelling. In the interim, household point-of-use interventions are needed to improve the microbiological quality of drinking water. Fewtrell and co-workers (2005) have reviewed 46 published publications on household interventions to determine the effectiveness of each type on intervention. According to this review, multiple interventions (combined water, sanitation and hygiene measures) were not more effective than interventions with single focus such as point-of use water quality interventions (Fewtrell *et al.*, 2005). This could have been due to the fact that studies showing negative outcomes on water, sanitation and hygiene aspects were not published (not accepted) or not even submitted for publication by the researchers (Fewtrell *et al.*, 2005).

In order for any intervention to be sustainable in a community, the environment must be supportive and the community must take ownership. Therefore, the chiefs and elders of the community must take the initiative to be part of the support system because the community respects their viewpoints. This aspect needs to be investigated further because several factors could play a role in the continued use of the system. These factors include: (1) knowledge of health, (2) knowledge of waterborne diseases, (3) hygiene, (4) proper storage of water containers and (5) proper handling of water containers (Sobsey, 2002). From the baseline survey it was evident that these communities have a lack of knowledge on all these factors. In order for any household water treatment and safe storage interventions to be successful, it must involve community education, participation and motivation (Nath *et al.*, 2006). Consequently, the communities must take responsibility for the treatment and safe storage of water in their own homes (Nath *et al.*, 2006).

5.3 TO DISTINGUISH BETWEEN FAECAL POLLUTION OF ANIMAL OR HUMAN ORIGIN USING MOLECULAR TYPING OF MALE SPECIFIC F-RNA BACTERIOPHAGE SUBGROUPS

It is important to determine the pathways of faecal contamination within the domestic household to decide on an effective point-of-use treatment system. Male specific F-RNA bacteriophage subgroups were used in this study to determine the origin of faecal pollution. The study was carried out specifically in rural households with a close living association with domestic animals and cattle. Differences in male specific F-RNA bacteriophages prevalence in the storage containers of households using different water sources were seen in this study. The prevalence of male specific F-RNA bacteriophages ranged between 30% and 65% for households using tap water and between 85% and 90% for households using river water. The higher prevalence of phages in the river water could have been due to animal and human activities in or near the river source. In addition, no difference between the traditional and CDC safe storage container water samples were seen with regards to the prevalence of male specific F-RNA bacteriophages. This is in agreement with the results from the formal intervention study indicating that the container without a sodium hypochlorite treatment is not improving the microbiological quality of the stored drinking water.

The results further demonstrated that water from the communal tap water and the household storage containers in village 1 were primarily contaminated by animal faecal matter because the majority of samples contained subgroup I male specific F-RNA bacteriophages (associated with animal faecal pollution). However, water from the river water sources and the household storage containers in village 2 were primarily contaminated by animal and human faecal matter because the samples contained subgroup I male specific F-RNA bacteriophages (associated with animal faecal pollution) and subgroup II male specific F-RNA bacteriophages (associated with human faecal pollution).

Consequently the results did give some indication of the origin of faecal pollution, but it was not conclusive due to the small sample size. In addition the results implied that the storage container does not prevent faecal contamination of stored drinking water in the absence of improved hygiene and sanitation behavior practices by the household members.

However, this is the first study to use male specific F-RNA bacteriophages to determine the origin of faecal pollution in household storage containers in rural households and the following aspects were identified for further research:

- (1) Survival of male specific F-RNA subgroups in households water storage containers. It would be important to investigate factors such as container type, storage conditions, role of temperature, pH and turbidity, water type, prevalence and role of biofilm in container and the survival period of different male specific F-RNA subgroups
- (2) Compare male specific F-RNA subgroups genotyping with new molecular PCR technique (Ogorzaly and Zantzer, 2006) to compare effectivity and costs
- (3) Determine the male specific F-RNA subgroups present in different animals from these rural communities to assess the specificity of male specific F-RNA subgroups typing as a source tracking technique.

5.4 TO DETERMINE THE SURVIVAL OF INDICATOR AND WATERBORNE PATHOGENS IN THE IMPROVED CDC SAFE STORAGE CONTAINER

This study demonstrated that home treatment of drinking water using the 3.5% sodium hypochlorite solution as stipulated by the DOH is a viable option for households without access to safe water supplies. Laboratory studies on the survival of indicator and seeded pathogens in the CDC safe storage container with or without the addition of a sodium hypochlorite solution indicated that the 3.5% sodium hypochlorite was more effective than the 1% sodium hypochlorite solution as expected. The 3.5% solution effectively reduced all the indicator and pathogenic microorganisms in the ground and river water samples within 60 min. However, the 1% solution was not as effective. In the ground water samples, the 1% sodium hypochlorite solution was effective in reducing heterotrophic bacteria, total coliforms, faecal coliforms, faecal enterococci, *E. coli*, *S. typhimurium*, somatic and male specific F-RNA bacteriophages within 60 min. While, in river water samples with a higher turbidity level (7.04 and 8.30 NTU), the 1% sodium hypochlorite solution was not effective and heterotrophic bacterial counts, *E. coli*, *S. typhimurium*, *C. perfringens*, male specific F-RNA bacteriophages and Coxsackie B1 virus were still detected from one to five days.

To date the only information available on the effect of disinfection procedures on microorganisms in the CDC safe storage container is based on *E. coli* and faecal coliforms (Sobsey, 2002; Sobsey *et al.*, 2003). Although seeding experiments from this study provided valuable information on the inactivation of organisms, the seeded microorganisms used may not be representative of naturally occurring microorganisms in ground and surface water samples (Tree *et al.*, 2003; Schaper *et al.*, 2002b). Additional studies on the survival of chlorine resistant parasitic protozoa (*Cryptosporidium* and *Giardia*) and various other enteric viruses (Hepatitis A, Rotavirus, Adenoviruses, Astroviruses and Noroviruses) are needed (Hambidge, 2001; Li *et al.*, 2002). However, it is difficult to detect and to determine viability of viruses from environmental samples since it requires cell culture methods and molecular based assays which are expensive. In addition skilled personnel are required to perform the viral and parasite analysis (WHO, 2005)

A comprehensive review by Sobsey (2002) has concluded that chlorination with storage in an improved vessel was one of five point-of-use technologies considered promising to be explored for communities without safe drinking water supplies. This study has showed that the CDC safe storage container together with a sodium hypochlorite solution can be promising for South African communities. In this study the CDC container and sodium hypochlorite solution as a point-of-use treatment system was accepted by the study communities and showed to be affordable for South African standards. However, more studies are needed on the long term utilization and sustainable use of this treatment system in rural communities of South Africa. It could therefore, be concluded that point-of-use treatments of water at the household level could provide effective health benefits to rural communities in the Vhembe region of the Limpopo Province of South Africa.

5.5 FUTURE RESEARCH NEEDS

In addition to the research needs mentioned in the previous section, important areas for further research have been identified. The prevalence of pathogenic microorganisms (eg. *E. coli* O157:H7, *Salmonella* spp, *Shigella* spp, *Vibrio cholerae*, Adenoviruses, Astroviruses, Noroviruses, Enteroviruses, Hepatitis A, Hepatitis E, Rotaviruses, *Giardia* and *Cryptosporidium*) in various water sources and stored water in household storage containers used by rural households should be determined. There is a lack of information regarding the prevalence of viruses, parasites and virulent bacterial strains in water sources and container stored water in rural communities. Pathogenic microorganisms have evolved mechanisms to rapidly adjust to changes in the environment (WHO, 2005). This may have implications regarding the infectivity, antibiotic sensitivity and pathogenicity of the microorganism. Research on microbial ecology and the investigation of virulence factors of the various heterotrophic microorganisms and other pathogenic bacteria such as *E. coli* and especially *E. coli* O157:H7, *Salmonella* spp and *Shigella* spp might assist in determining the health risk. This may have major health implications for high risk individuals such as the young, the elderly and immunocompromised people consuming this water.

Advanced analytical methods should be used to help discriminate between introduced pathogenic and naturally occurring non-pathogenic strains of waterborne microorganisms and to characterise the emergence of new strains of pathogens as a result of genetic changes. This analysis could be conducted using molecular and genotyping techniques. Molecular typing and sequencing of the isolates will provide valuable information on the origin of the specific microbial species and their relatedness (Lebuhn *et al.*, 2004; Rousselon *et al.*, 2004; Wang *et al.*, 2004; Wei *et al.*, 2004). Consequently, if a link between environmental and clinical isolates could be established in rural communities, appropriate action can be taken by the DOH and the Department of Water Affairs to prevent the risk of waterborne diseases. Burden of disease and risk-associated studies can also be conducted if more information on bacterial pathogens, viruses and parasites are available.

Additional studies are needed based on the antibiograms of the isolated opportunistic and pathogenic bacterial isolates from unprotected and protected water sources as well as for bacterial isolates obtained from water and biofilms inside the storage containers. Although antibiograms are known to vary from place to place and with time, necessitating the need for periodic updates in order to uncover resistance patterns, there are no baseline data on antibiograms of potential bacterial pathogens of diarrhoea isolated from diarrhoeic stool specimens in rural communities in the Vhembe region of South Africa. An urgent need, therefore, exists to ascertain the incidence of enteric pathogens in diarrhoeic stools, as well as antibiograms of these bacterial isolate. These studies would assist in assessing the presence of resistant microorganisms circulating in a community. Additional information will be provided regarding the health risk these resistant bacteria hold for high risk individuals that are exposed to these microorganisms (Obi *et al.*, 2002; Obi *et al.*, 2004).

The possible zoonotic risk prevalent in these communities has not received much attention. Several studies have reported a link between animal pathogens and isolates obtained from humans (Meslin, 1997; Sinton *et al.*, 1998; Franzen and Muller, 1999; Slifko *et al.*, 2000; Enriquez *et al.*, 2001; Hoar *et al.*, 2001; Leclerc *et al.*, 2002; Theron and Cloete, 2002; Hackett and Lappin, 2003). Genetic and phenotypic characteristics of pathogenic microorganisms are needed to explain zoonotic relationships of

microorganisms with their animal hosts to determine factors that may influence their transmission to humans. Most of these communities are at risk of contracting diseases from animals due to the close living association between domestic animals, cattle and people in rural areas of South Africa.

In addition the effect of human and animal activities on water sources should also be investigated in more detail: (1) human sewage and animal excreta in surface water in communities with inadequate sanitation infrastructure could increase the nitrogen and phosphate levels of water used for drinking , (2) phosphates levels in water where rural woman wash their clothes or people bath and (3) irrigation of crops with pesticides and fungicides increases the levels of organophosphates, copper and mercury. These same water sources are used for drinking water collection and little is known on the health effect of these activities on people in rural areas. Data on these factors will assist in effective water treatment and intervention policies.

Another aspect is the lack of information on the role of toxins produced by bacteria such as the *Cyanobacteria* as well as their role in waterborne diseases (WHO, 2005). *Cyanobacteria* have been identified at causing hay fever, eye irritations, skin rashes, vomiting and diarrhoea (WHO, 2005). In addition, research on different chemical compounds, heavy metals, endocrine disrupting compounds (EDC) to determine the health risk to consumers in regions without adequate water infrastructures are important. Mining activities increase mineral and salts in water, affects the pH of the water and increase the presence of metals such as nickel, zinc, cadmium and lead which can build up in fish and animals which are eaten by the communities (DNR, 2006). Insecticides such as DDT which are used in South Africa for control of the malaria mosquito could also be washed into surface and groundwater sources during rains. Accumulation in fish and animals drinking the water can occur, ultimately reach humans who consumes these animals as part of their daily food intake.

Finally, an important aspect that is not addressed adequately in intervention studies is the promotion of sustainable behavior changes to improve basic hygiene and sanitation practices in these rural communities (Fewtrell *et al.*, 2005). The only way the behavior of a household or community will be sustained is when (1) the environment is

supportive (media involvement, policy makers involvement and resources provided); (2) delivery systems is sufficient (services must be available, products must be available and the Department of Health must promote behavior changes); (3) communities must take ownership and have support groups and (4) individual household members must be motivated, have positive attitudes about behavior changes and proper resources must be available to the household (knowledge and skills impartation). It is necessary to involve the female head of the household in all intervention strategies and involve community women groups and faith based organisations with which people can associate to effect behavior changes. Studies are needed which will investigate the integration of education on health aspects and training on basic hygiene and sanitation practices of the existing health infrastructure. These educational studies need to address and monitor behavioral patterns in the households. Although people know that water can be contaminated, they are ignorant of the effect of how some of their actions could contribute to the faecal pollution of the drinking water at the point-of-use (Dunker, 2001). Very little information on how households allocate water to different purposes within the household is available. It is important to establish the sequence of the type of water supply, sanitation and hygiene interventions produce the greatest health benefits for these communities. These studies need to provide information on the prevalence and survival of a broad spectrum of selected pathogenic microorganisms in stored household water particularly in households where high-risk individuals are living. This information will assist in formulating policies on health and sanitation for developing communities to assess rural water supply needs and to determine whether the water is used efficiently.

Research on all these aspects will be of extreme importance in water quality studies and will provide valuable data to improve the microbiological quality of water stored at the rural households, prevent the transmission of waterborne diseases and provide people living with immunocompromised diseases with safe drinking water. The results of these studies will assist various role players in the South African government in the formulation of policies regarding water, sanitation and hygiene aspects and changes in South Africa to improve the general well being of the people of South Africa.