

Systematic risk management approach of household drinking water from the source to point of use.

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Abstract

The Water Safety Plan (WSP) approach is being widely adopted as a systematic approach to improving the safety of drinking water. However, to-date the approach has not been widely used for improving the safety of drinking water in those settings where people have to collect water away from their home. Most rural areas in South Africa still consume unsafe water despite WSP implementation and improved water sources provided by Municipalities. This study used HACCP to assess drinking water used in households to determine systematic procedures, which could be used to control risks. The process includes assessment of risks associated to household water service level (availability, accessibility and potability) and risks of water contamination from the collection to point of consumption. Observations and questionnaires were used to collect data in households to systematically determine and identify risks of drinking water consumption. The results show intermittent water supply, access to unsafe water, whilst poor hygiene practices contribute to household water contamination. This approach could assist in identifying hazards as well as critical control points to reduce risks and improve management of drinking water safety in households.

Key words: Drinking water quality, Hazard Analysis Critical Control Point, households, Risk assessment, Water Safety Plans, Water sources

Introduction

The safety of drinking water relies on an assessment and control of risks from the catchment to the point of use (Rickert *et al.* 2012). If appropriate risk assessment and risk management is undertaken then drinking water should achieve an acceptable or at least a tolerable risk of adverse health effects. It is unfortunate, therefore, that in many areas of developing countries still depend on unsafe water sources. Most effort is directed at identifying and controlling risks associated with problems at the source and in distribution and there is less effort given to reduce risks associated with contamination at the point of use (Evans *et al.* 2013). The World Health Organization (WHO) now recommends the Water Safety Plan (WSP) approach, which is currently used by many countries worldwide to improve the status of drinking water (Davison *et al.* 2006). This approach was adapted from the concept of Hazard Analysis Critical Control Point (HACCP), regulated for food industries since 1990's (Codex Alimentarius 1997). The HACCP concept recommends seven steps of which only four was used for this study since its aim is to identify the hazards and its control measures. The steps include: engaging team who are responsible for water supply used from the point of collection to the point of use, analyses of hazards which could contribute into significant risk and critical areas where hazards could prevail, how risks in those areas can be controlled by checking the extent to which such hazards are controlled and compare risks with available critical limits (WHO 1997). The critical limits include water service indicators and water standard to verify the extent of risks.

In South Africa, risk management of drinking water in rural areas is done from catchment up to the supply point on the street (Department of water Affairs [DWA] 2009). From that point the consumer is responsible to manage their drinking water from point of collection to consumption. A South African quality scheme known as Blue Drop (risk assessment of drinking water) encourages all municipalities to take part in drinking water risk assessment to ensure safe water provision to their communities (DWA 2011). However, within the Blue Drop scheme less effort is directed as ensuring that consumers have sufficient access (25ℓ/c/d Litres/capita/day) or whether water is still potable at the point of consumption. Also the Blue Drop scheme is not particularly useful for small water systems. For small systems, communities are generally left to manage their own water supplies. This lack of involvement in small water supply systems has resulted in unsafe water usage, poor handling and practices, which has been associated with increased chance of water contamination and burden of diarrhoea (Hunter *et al.* 2010; Rufener *et al.* 2010; Shwe 2010; Sorlini *et al.* 2013).

Understanding the state of the water supply and its associated risks as an early part of WSPs is crucial for risk identification. The type of water sources used (improved or unimproved sources) and the availability of a sanitary system in a household could play a critical role in determining hazards during HACCP implementation. WHO/UNICEF (2012) describe improved drinking water as the use of piped water connected in household yard, public tap, tube well or borehole, protected spring, protected dug well and rain water collection. Whereas, unimproved water sources include unprotected dug well, unprotected spring, tanker truck, surface water and bottled water. Unimproved sources are those sources which can easily be contaminated and cause health risks to the consumers. As an aid to categorising the risks in drinking water, Davison et al. (2006) and Batram *et al.* (2009) recommended a scoring matrix. This matrix has two dimensions, the first indicating the severity of impact of the event on public health and the second the probability of occurrence. Severity is graded risk from 1 to 4 (low, middle, high and very high) and probability of occurrence from 1 to 5 (1-Rare; 2-Unlikely; 3-Moderately likely; 4-Likely and 5-Almost likely).

This paper reports the use of a HACCP approach to assessing the risks of small water systems in South Africa using the risk categorisation approach described above.

Methods

The current study was conducted in rural villages of Limpopo province in South Africa. There were nine villages experiencing water scarcity and were grouped as village 1 (A-I) villages and one village with plentiful water supply and was referred as village 2. Permission was granted by the village leaders, Water Service Authority (WSA) and the participants prior to any data collection.

We used a modified HACCP analysis to assess risks to public health from problems arising at the point of water supply to the point of use in the household. We used a two stage process. The first stage was a “pre-requisite” analysis undertaken that was undertaken before the actual on-site risk assessment sites (Mortimore 2000; Swierc *et.al.* 2005). Pre-requisite analysis is a survey that is conducted to assess the water service within the area, which begins with formulation of the team involved in water supply chain. We contacted the village leaders who contacted all participants who played a key role in water supply chain. We had a meeting with all participants to outline the details of the study. We then conducted a workshop composed of community leaders, water operators and environmental health

Practitioners (employed by WSA; rendering their services in villages where study was conducted) to assess the role of each participants in the water supply chain from the point of collection to the point of use. The water service level that included the type of water sources used and their availability, accessibility and potability in villages was also assessed. The objective of the workshop was for the researchers and community to obtain information on the type of water sources used by the community and the risks involved. An onsite survey was held by visiting each water source and obtaining description of challenges attached to it. As part of the workshop, visits to the households to assess the water safety management practices were made to outline the type information required by the researchers and field workers regarding households when conducting risk assessment. The information on water supply obtained during the workshop was discussed and enable the researchers to be aware of the risks faced by the communities prior to onsite risk assessment in the households. The researchers and field workers subsequently continue with household's survey referred as onsite assessment.

Onsite risk assessment is the secondary stage of risk assessment, which begins from the collection point and involves the transportation, storage and point of use. This stage is mainly concerned with how water is managed, by assessing the environmental health practices, hygiene and safety of water at the point of use. Onsite risk assessment was done by the researcher, fieldworkers and the owner of the households through observation and questionnaires.

Global Positioning System was used to record the distribution and functionality of the water points. Ozi-explorer software was used to indicate how the water points were distributed within the villages (Ozi-explorer, 2010). Onsite-information, obtained from the households, was given by the respondents who were responsible for providing water in households. A questionnaire was used to obtain information in household, which included type of water sources used and environmental health practices, whilst observation was used to assess hygiene practices related to drinking water safety management in the households.

The analysis of water service level was based on the 1994 *Water Supply and Sanitation Policy* White Paper of South Africa (DWA 1994). The critical limit on accessibility is indicated as the distance travelled from household to a water source, which should not exceed 200m (one way trip). It further states that an alternative water supply should be provided if

water is not available for 24 hrs, any interruption of water should not exceed three consecutive days and every person in a household should access at least 25ℓ per day. Moreover, the critical limit measurement of potability states that all drinking water sources should not contain *E. coli* (</100mℓ) and should exceed 10/100mℓ colony-forming-unit (CFU)/100mℓ for total coliform count (South African Bureau of Standard 2011). Water samples were taken from 120 households in both villages. Two samples were taken from 120 households; one taken from water container while the second sample was taken from the source where water was drawn. A sterile 1ℓ container was used to collect each sample that was subsequently stored in a cooler bag at 4°C and transported to the laboratory and analysed within six hrs using the Idexx Colilert®-18 method (Idexx 2001).

Data analysis

The South African *Water Supply and Sanitation Policy* White paper of 1994 was used to determine the critical control limits and analyse risks brought by outcomes of water service (DWA 1994). However to measure potability of water; South African National Standard 241-2011 was used (South African Bureau of Standard 2011). To manage the data, all questionnaire and observation data was entered into SPSS version 18 where it was cleaned and analysed. A Kruskal-Wallis test was used to compare distances and *E-coli* counts at a statistical significance difference of 95% confidence level using p-value of 0.05.

Risk assessment.

The study used the risk matrix adapted from Davison et al.(2006) and Batram et al. (2009) to measure the risks, using scores from 1 to 4 and to explain the consequence of each score. The hazards analysis, hazards events and control measure were adapted from Pérez-Vidal *et al.* (2013). The two tables were constructed to distinguish between hazard assessment and risk analysis whereas the second table suggests risk control matrix based on the outcomes of the study. Identification of a team, hazard analysis, critical control limit and control measures were conducted using risk matrix score of 1 to 4. The risk matrix used were no impact (1), tolerable (2), peripheral (3) and not tolerable (4), adapted from Davison et al., 2006. Consequences include no health impact (1), minimal impact causing dissatisfaction and health concern (2), marginal impact which can cause health risk (3) and major impact with

serious health consequences (4). Risk estimation was shown with and without control measures. The use of this criteria aimed at identifying the systematic risk assessment procedure used to determine critical control points.

Results

A total of 201 households were recruited to participate in the study. One hundred and twenty households were sampled from village 1(A-I) with a scarcity of water, whereas 81 households were sampled from village 2 with a plentiful water supply using various sources.

Accessibility and water sources used

Information obtained from community leaders, WSA, household respondents and GPS showed that both village 1 (A-I) and 2 use improved and unimproved water sources. The distance travelled to access tap water in both villages was less than 200m whereas distance travelled to spring water in village 2 was up to 5km. In village 1 (A-I), 24% of households used their own drilled wells as a primary water supply and 72% used communal taps on the street, whilst the remaining 4% used other sources. Privately drilled wells and tank water was used as the main secondary sources. Village 2 used both communal sources (75%) and springs (21%) and 4% used other sources. The secondary source used is spring water. Furthermore, 63% of village 1(A-I) households did not have water on-site and only 37% have water in their own yards; whilst 4% do not have any form of sanitary system. Forty six percent of households in village 2 had taps in their own yard and 54% did not have taps. Around 7% did not have sanitary system. At times, water was not available from sources for up to 60 days, and the secondary sources were used as an alternative water source. The most reliable source was water from the spring followed by private drilled wells. Most communities used mixed sources for drinking purposes and other domestic chores due to intermittent water supply from communal standpipes. Table 1 shows that most people travel more than 200m to access water from the spring (49%) and to access tank water (38%). Kruskil-Wallis test shows the significant difference of $P < 0.01$ between distances travelled to water sources.

Table 1: Distance travelled to water source (%)

Hygiene and household water practices

During the survey, 232 containers were checked for cleanliness; 10% were found to have biofilm, 42% with loose particles and 48% were found clean. Clean containers were seen as being without scratches, biofilm or any foreign layers inside. Approximately 59% of households used soap, or water and sand mixed with soil found on the ground to clean the containers.

Water quality

Total coliforms recorded were 76% of the water sources and 84% of the water stored in containers; *E. coli* counts were in 37% of the water sources and in 39% of the stored water. There was an increase in water contamination from the source to water kept in containers. An independent sample Kruskal-Wallis test showed a significant difference ($p < 0.001$) in drinking water sources. *E. coli* concentration was recorded high in spring water compared to other sources as indicated in Table 2.

Table 2: Microbiological water quality of water sources and container water (%)

Systematic Procedure used to determine risks in household drinking water.

As part of team engagement, the researchers included all the stakeholders responsible for water supply chain. This comprised community leaders and WSA officials that included village water operators and Environmental Health Practitioners who were responsible for assessment of risks related to environmental health practices. The main responsibility of the team was to assess the service delivery and liaise with WSA on matters related to water service. The inclusion of WSA officials and village leaders in this research was critical in determining the systematic risk procedure that identifies risks in household drinking water. Their involvement in the description of water systems and identification of hazards in terms of water availability, accessibility and potability as outlined in Table 3 was crucial. The findings were based on the information obtained from the team. This step is regarded as a

pre-requisite risk analysis as it assist the researcher in becoming aware of the risks that could jeopardise the effectiveness of on-site risk assessment. The researchers suggest that when systematic household risk assessment is done description of water system should be regarded as the first step to be considered prior to onsite risk assessment. The pre-requisite assessment provide information that could deter the systematic analysis of risks at household level. The results showing intermittent water supply, distance travelled and the use of both improved and unimproved water sources; require precautionary measures to be taken prior to consumption of water. The safety of drinking water used supplied by WSA and secondary sources used is not guaranteed. This was verified through the assessment of water quality at the sources used by communities as indicated in figure 1.

The pre-requisite risk assessment was followed by on-site risk assessment which involved the identification and assessment of hazards from collection and point of use at household level as outlined in Table 3. This was informed by the findings and information provided by community members. The results were benchmarked to water service indicators which are described as critical limits as appeared in the (1994) South African *Water Supply and Sanitation Policy* White paper and Howard and Bartram (2003). On-site risk assessment began from the point of collection to the point of use and the hazards and risks identified, were based on the findings from on-site assessment. Furthermore, Table 3 identifies the hazards which were attributed to poor water services and unhygienic practices from water collection to the point of use outlining areas where critical measures should put in place. Table 4 show the estimated risk and impact on each activity which could cause hazards that could affect water quantity, water quality, hygiene and effect attributed by container design, as outlined in Table 3. The risks were further estimated with and without control measures to further indicate how the suggested control measures could reduce the risks.

Table 3: Hazard analysis if drinking water from pre-requisite assessment to the point of use adapted from Pérez-Vidal *et.al* (2013)

Risk analysis criteria	Activity and procedure of risk assessment	Hazard event	Critical Limits	Type of hazard			
			(DWA 1994)	Water Quantity	Water Quality	Hygiene	Structural Design
Pre-requisite hazard analysis	1. Accessibility	-Distance travelled to improved water source less than 200m -Unimproved water sources closer to households and the furthest at more than 5km	- Distance travelled to the source should not exceed 200m	X	X	X	
	2. Availability	-Communal water sources not available for up to 6 months - Unimproved water sources used as secondary source and are reliable.	-25ℓ/c/d water should be available to each person.	X	X X	X X	
	3. Potability	-Contaminated communal water used for consumption -Contaminated secondary sources used for consumption -The use of unimproved sources -Use of contaminated water stored in containers -Private boreholes located next to sanitary facilities (septic tanks, cow shed, toilets etc.)	-Total coliform counts should not exceed 10/100mℓ - <i>E. coli</i> should not be found in water (<1/100mℓ)		X X X X X	X X X X	X
On-site risk assessment from collection point to the point of use	4. Collection point	-water accessed from taps, springs, tanks and private drilled wells -Dirty containers used for water collection (showing scratches, biofilm and moving particles) -Hands dipped inside drinking water during collection.	Not determined		X X	X X	X X
	5. Transportation	-Dirty wheelbarrow load used for water transportation -Water transported in dirty containers without lids in dusty roads -Water transported by head with hands dipped inside	Not determined		X X X	X X X	X X X
	6. Storage	-Water stored in dirty containers -Soil mixed with soup is used to clean containers -Water stored in containers without the lids exposed to dust -Water stored in dusty house	Not determined		X X X X	X X X X	X X

	Point of use	-Dirty scooping vessels used to scoop water from the storage container -Dipping hands in drinking water	Not determined		X	X	X
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Table 4: Risk assessment matrix in household water Adapted from Pérez-Vidal *et al.* (2013)

Activity and risk assessment №	Risk estimation without control measure		Corrective measures	Risk estimation with control measure	
	Hazard №	Consequence		Risk score	Consequence
1. Accessibility	4 Major impact with serious health consequence	Not tolerable (4)	Provision of safe water to reduce distance, prolonged waiting time and use of unimproved water sources.	Marginal impact which can cause health risk	Peripheral (3)
2. Availability	Major impact with serious health consequence	Not tolerable (4)	Disinfection of water obtained from unsafe sources Health education and awareness	Minimal impact causing dissatisfaction and health concern	Peripheral (2)
3. Potability	Major impact with serious health consequence	Not tolerable (4)	Health education on good water storage and hygiene practice at home Conduct environmental impact assessment before construction of sanitary or water system	Minimal impact causing dissatisfaction and health concern	Tolerable (2)
4. Collection point	Major impact with serious health consequence	Peripheral (3)	Health education on good water storage, hygiene and treatment	Minimal impact causing dissatisfaction and health concern	Tolerable (2)
5. Transportation	Major impact with serious health consequence	Not tolerable (4)	Clean and disinfect transport used for transporting water Health education and awareness on hygiene practices at home	Minimal impact causing dissatisfaction and health concern	Tolerable (2)
6. Storage	Major impact with serious health consequence	Not tolerable (4)	Health education on good water storage, hygiene and treatment	Minimal impact causing dissatisfaction and health concern	Tolerable (2)
7 Point of use	Marginal impact which can cause health risk	Peripheral (3)	Health education and awareness on good hygiene practices at the point of use	Minimal impact causing dissatisfaction and health concern	Tolerable (2)

Discussion

An effective risk assessment and risk management approach in household drinking water is fundamental to ensuring the safety of drinking water. In this paper we have used a HACCP approach to characterise the risks to drinking water associated with problems developing between the source and the tap in rural South Africa. This approach seeks to understand detailed information on the supply of tap water by WSA in villages that could affect the process of risk assessment prior to on-site assessment of water safety management in households from the collection to the point of use. Although the HACCP approach and the WSP small community systems are similar, the HACCP used for household water safety distinguishes pre-requisite and on-site risk assessment approaches used (WHO, 2012). However, this study focuses on the collection of water from the tap provided by WSA. This study addresses the typical situation of what is happening in South Africa where taps are provided, hence there is no continuous supply. However the study also seeks for better management of household water at household level aiming at reduction of contamination at the point of use. Therefore the study findings show risks that are likely to have severe consequences, with effective control measures that are anticipated to reduce risks considerably.

The pre-requisite assessment determined the status of water service delivery in the villages before risk analysis from the collection point to households, to identify any limitations in HACCP implementation (Swierc, *et al.* 2005). Intermittent water supply, household water storage to consumption point, poor water quality and unhygienic conditions were found to be the main risks in villages where the study was conducted. The findings identified hazards constraints affecting water quantity, quality and hygiene that could be addressed through training on the appropriate use of containers during the implementation of the HACCP process in households.

There were few household recorded without toilet. Observations clearly indicated that most of those sanitary facilities were not hygienically clean and not capable of preventing flies and groundwater contamination. The majority of such toilets were situated close to private drilled wells, a finding confirmed by VDM study (Potgieter *et al.* 2006). Inadequate sanitation and unsafe water consumption could lead to diarrhoea (Hunter *et al.* 2010). Consumption of water sources contaminated by both total coliforms and *E. coli* highlight the precautionary

measures that should be taken during on-site risk assessment from collection to point of use to prevent diarrhoea cases (Brown *et al.* 2008). Though communal sources were less contaminated compared to secondary sources, the use of privately drilled wells and springs was of concern as contamination was very high. Similar situations were found in both developed and developing countries (Boone *et al.* 2011; Gelting 2009; Peter 2010; Waga *et al.* 2010; Atusinguza and Egbuna 2012). Springs and privately drilled wells were found to be more reliable compared with communal taps provided by municipalities. A study by Hunter *et al.* (2009) indicated that the provision of water infrastructure is ineffective if not supported by a reliable water supply. Additionally, Majuru *et al.* (2010) indicated that an unreliable water supply increases the burden of diarrhoea.

The use of containers to store water was more common with an unreliable water supply and the access of water on the street and is one of the barriers obstructing the sustainability of good water quality in households. Consequently, poor hygiene observed could be the main contributory factor of the deterioration of the quality of water stored in containers, as suggested by Shwe (2010); Mokoena (2009); Pickering and Davis (2012) and La Freniere (2008). The design of containers also contributed to poor water quality (Shwe 2010). However distance to water source could also influence the use of unsafe water source as suggested by La freniere (2008). Therefore, intervention measures that are employed before water consumption in households could decrease the anticipated risks in water (Clasen 2009; Rosa and Clasen 2010). The contamination of water sources indicate risks that could occur in household if prior treatment is not done.

Of the seven HACCP steps, study considered only four steps, which included formulation of a team, description of water system, identification of hazards, risks and events and control measures, critical control limits. The water analysis was only done to support and provide evidence of the findings. However, the study only suggest control measures without improvements plan. The control measures suggested was based on the general control measures used.

Conclusion and recommendations

Drinking water used by the communities was of poor quality and posed a health risk to consumers. Using the HACCP approach we were able to identify key risks to drinking water safety and estimate the benefits from interventions to improve drinking water safety. The intermittent water supply, was rated as one of the more serious hazards with high risk to

communities impacting on water quality. Involvement of stakeholders in risks identification, supported by education and awareness, plays an important role in providing information on how water should be managed to maintain its safety. This can only be done when hazards are known and control measures could be implemented. The contamination of water sources and increased contamination in water kept in containers verify the available risks and support the need for prerequisite and onsite risk assessment for public health gain. The process ensures risks are identified on time and appropriate measures are taken to control the situation. This study concluded that areas where control measures were recommended could serve as critical control points. Therefore, need for systematic risk assessment is essential to identify risks that could contribute to water contamination at the point of use. It is recommended that the implementation of systematic HACCP approach in South African households, requires involvement of WSA's, Environmental Health Practitioners, community leaders, and household members to support and provide training; consumers and community leaders before consumption. An increase in contamination from water stored in containers could be an indication of poor hygiene and environmental health practices in household. The study suggests that where mixed sources are used the provision of safe tap water provided by WSA's could not benefit the consumers. It could also confuse the entire process of risk assessment in household if not identified. Studies done by Gundry *et al.* (2004) recommended intervention measures which include safe water storage and treatment, supported by health education to improve water quality and decrease diarrhoea.

Therefore, hazards identified in pre-requisite risk assessment and on-site risk assessment determine the critical control points. The use of the modified HACCP approach to detect risks in drinking water and develop measures to eliminate or reduce the hazards identified is critical for consumer safety.

Acknowledgement

The researchers would like to acknowledge the Medical Research Council of South Africa, Tshwane University of Technology, for funding, the Wellcome Trust for capacity building and Matodzi Michael Mokoena and Renay Van Wyk during data collection. The support given by Sinthumule leaders and Vhembe District Municipality for the entire study is also acknowledged.

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