## Research Paper

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

Lutendo S. Mudau, Murembiwa S. Mukhola and Paul R. Hunter

## 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 hazard analysis critical control point 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 with 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, while 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

**Lutendo S. Mudau** (corresponding author)
Department of Environmental Health,
Tshwane University of Technology,
P/Bag x680,
Pretoria 0001,
South Africa
E-mail: *mudauls@tut.ac.za*

**Murembiwa S. Mukhola**
Tshwane University of Technology,
P/Bag x680,
Pretoria 0001,
South Africa

**Paul R. Hunter**
The Norwich Medical School,
University of East Anglia,
Norwich NR4 7TJ,
UK

## INTRODUCTION

The safety of drinking water relies on an assessment and control of risks from the catchment to the point of use (Ricket *et al.* 2014). 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 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 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 the 1990s (Codex Alimentarius 1997). The HACCP concept recommends seven steps, of which, only four were 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 to significant risk and critical areas where hazards could prevail; how risks in those areas can be controlled by checking the extent to which



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such hazards are controlled; and compare risks with available critical limits (WHO 1997). The critical limits include water service indicators and water standards 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 at ensuring that consumers have sufficient access (25 L/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 the 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 can 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. 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 Bartram *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 these were grouped as village 1 (A-I) villages and one village with plentiful water supply which was referred to 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 that was undertaken before the actual on-site risk assessment (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 the water supply chain. We contacted the village leaders who then contacted all participants who played a key role in the 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 the study was conducted) to assess the role of each participant 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 on-site survey was held by visiting each water source and obtaining a description of the 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 of 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 enabled the researchers to be aware of the risks faced by the communities prior to on-site risk assessment in the households. The researchers and field workers subsequently continued with the household survey, referred to as on-site assessment.

On-site 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. On-site risk assessment was done by the researcher, field workers and the owners of the households through observation and questionnaires.

The Global Positioning System (GPS) 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). On-site 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 households, which included type of water sources used and environmental health practices, while 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 200 m (one-way trip). It further states that an alternative water supply should be provided if water is not available for 24 hr, any interruption of water should not exceed 3 consecutive days and every person in a household should have access to at least 25 L per day. Moreover, the critical limit measurement of potability states that all drinking water sources should not contain *Escherichia coli* (</100 mL) and should exceed 10/100 mL colony-forming unit (CFU)/100 mL 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 the water container while the second sample was taken from the source where water was drawn. A sterile 1 L container was used to collect each sample which was subsequently stored in a cooler bag at 4 °C and transported to the laboratory and analysed within 6 hr 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 were 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 a $p$-value of 0.05.

## Risk assessment

The study used the risk matrix adapted from Davison *et al.* (2006) and Bartram *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-Vida *et al.* (2013). Table 1 was constructed to distinguish between hazard assessment and risk analysis whereas Table 2 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 the risk matrix score of 1 to 4. The risk matrix scores 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 these criteria aimed at identifying the systematic risk assessment procedure used to determine critical control points.

**Table 1** | Hazard analysis of drinking water from pre-requisite assessment to the point of use, adapted from Pérez-Vida *et al.* (2013)

| Risk analysis criteria | Activity and procedure of risk assessment | Hazard event | Critical limits (DWA 1994) | Type of hazard | | | |
|---|---|---|---|---|---|---|---|
| | | | | Water quantity | Water quality | Hygiene | Structural design |
| Pre-requisite hazard analysis | 1. Accessibility | Distance travelled to improved water source less than 200 m; Unimproved water sources closer to households and the furthest at more than 5 km | Distance travelled to the source should not exceed 200 m | X | X | X | |
| | 2. Availability | Communal water sources not available for up to 6 months | 25 L/c/d water should be available to each person | X | X | X | |
| | | Unimproved water sources used as secondary source and are reliable | | | X | X | |
| | 3. Potability | Contaminated communal water used for consumption | Total coliform counts should not exceed 10/100 mL; *E. coli* should not be found in water (<1/100 mL) | | X | X | |
| | | Contaminated secondary sources used for consumption | | | X | X | |
| | | Use of unimproved sources | | | X | X | |
| | | Use of contaminated water stored in containers | | | X | X | X |
| | | Private boreholes located next to sanitary facilities (septic tanks, cowshed, toilets, etc.) | | | 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 | Not determined | | X | X | XX |
| | | Dirty containers used for water collection (showing scratches, biofilm and moving particles) | | | X | X | X |
| | | Hands dipped inside drinking water during collection | | | | | |
| | 5. Transportation | Dirty wheelbarrow load used for water transportation | Not determined | | X | X | X |
| | | Water transported in dirty containers without lids in dusty roads | | | X | X | X |
| | | Water transported by head with hands dipped inside | | | X | X | X |
| | 6. Storage | Water stored in dirty containers | Not determined | | X | X | |
| | | Soil mixed with soap is used to clean containers | | | X | X | X |
| | | Water stored in containers without the lids and exposed to dust | | | X | X | X |
| | | Water stored in dusty house | | | X | X | |
| | 7. Point of use | Dirty scooping vessels used to scoop water from the storage container | Not determined | | X | X | X |
| | | Dipping hands in drinking water | | | | | |

**Table 2** | Risk assessment matrix in household water, adapted from Pérez-Vida *et al.* (2013)

| Activity and risk assessment no. Hazard no. | Risk estimation without control measure | | Corrective measures | Risk estimation with control measure | |
|---|---|---|---|---|---|
| | Consequence | Risk score | | Consequence | Risk score |
| 1. Accessibility | 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) |

## 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 200 m whereas the distance travelled to spring water in village 2 was up to 5 km. 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, while the remaining 4% used other sources. Privately drilled wells and tank water were 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; 4% do not have any form of sanitary system. Forty-six per cent of households in village 2 had taps in their own yard and 54% did not have taps. Around 7% did not have any 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 3 shows that most people travel more than 200 m to access water from the spring (49%) and to access tank water (38%). The Kruskal–Wallis test shows the significant difference of $p < 0.01$ between distances travelled to water sources.

## Hygiene and household water practices

During the survey, 232 containers were checked for cleanliness; 10% were found to have a 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 as high in spring water compared to other sources, as indicated in Table 4.

## Systematic procedure used to determine risks in household drinking water

As part of team engagement, the researchers included all the stakeholders responsible for the water supply chain. This comprised community leaders and WSA officials that included village water operators and environmental health

**Table 3** | Distance travelled to water source (%)

| Water source | No. | 0–10 m (%) | > 10– ≤ 50 m (%) | > 50– ≤ 100 m (%) | > 100– ≤ 200 m (%) | > 200 m (%) |
|---|---|---|---|---|---|---|
| Communal standpipe | 79 | 17 (22) | 14 (18) | 10 (13) | 14 (18) | 24 (30) |
| Borehole | 6 | 1 (17) | 1 (17) | 3 (50) | 0 | 1 (17) |
| Tank | 8 | 2 (25) | 2 (25) | 1 (13) | 0 | 3 (38) |
| Spring | 66 | 5 (8) | 6 (9) | 2 (3) | 21 (32) | 32 (49) |
| Private drilled well | 58 | 31 (53) | 9 (16) | 4 (7) | 2 (3) | 12 (21) |
| Total | 217 | 56(26) | 32(15) | 20(9) | 37(17) | 72(33) |

**Table 4** | Microbiological water quality of water sources and container water (%)

| | | | Water at source | | | | Container water | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CFU/100 mL | Types of water sources | No. | < 1 (%) | 1–10 (%) | 11–100 (%) | > 100 (%) | < 1 (%) | 1–10 (%) | 11–100 (%) | > 100 (%) |
| Total coliforms* | Communal tap | 50 | 25 (50) | 11 (22) | 2 (4) | 12 (24) | 10 (20) | 6 (12) | 7 (14) | 27 (54) |
| | Private drilled well | 26 | 0 | 4 (15) | 3 (12) | 19 (88) | 0 | 4 (15) | 5 (19) | 17 (66) |
| | Spring | 33 | 2 (6) | 0 | 0 | 31 (94) | 9 (27) | 1 (3) | 4 (12) | 19 (58) |
| | Tank | 11 | 2 (18) | 0 | 4 (36) | 5 (45) | 0 | 0 | 2 (18) | 9 (81) |
| | Total | 120 | 29 (24) | 15 (13) | 9 (8) | 67 (56) | 19 (16) | 11 (9) | 18 (15) | 72 (60) |
| *E. coli** | Communal tap | 50 | 41 (82) | 6 (12) | 2 (4) | 1 (2) | 33 (66) | 9 (18) | 3 (6) | 5 (10) |
| | Private drilled well | 26 | 21 (81) | 2 (8) | 1 (4) | 2 (7) | 15 (58) | 6 (23) | 4 (15) | 1 (4) |
| | Spring | 33 | 4 (12) | 17 (52) | 11 (33) | 1 (3) | 17 (52) | 6 (18) | 8 (24) | 2 (6) |
| | Tank | 11 | 9 (82) | 1 (9) | 0 | 1 (9) | 8 (73) | 1 (9) | 1 (9) | 1 (9) |
| | Total | 120 | 75 (63) | 26 (22) | 14 (12) | 5 (5) | 73 (61) | 22 (18) | 16 (13) | 9 (8) |

*Kruskal–Wallis test = $p < 0.001$ (significant difference between water sources).

practitioners who were responsible for the 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 are based on the information obtained from the team. This step is regarded as a pre-requisite risk analysis as it assists the researcher in becoming aware of the risks that could jeopardise the effectiveness of on-site risk assessment. Researchers suggest that when systematic household risk assessment is done, description of the water system should be regarded as the first step to be considered, prior to on-site risk assessment. The pre-requisite assessment provides 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 highlight the need for precautionary measures required prior to water consumption. 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 Table 4.

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 1. 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 appearing in the (1994) South African *Water Supply and Sanitation Policy* White paper and Howard & 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 1 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 be put in place. Table 2 shows 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 1. The risks were further estimated with and without control measures to further indicate how the suggested control measures could reduce the risks.

## 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 the 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 hazard 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 households recorded without a 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 a 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 cases of diarrhoea (Brown *et al.* 2008). Although 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 (Gelting 2009; Peter 2010; Wagah *et al.* 2010; Boone *et al.* 2011; Atusinguza & 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 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 & 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 sources 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 & Clasen 2010). The contamination of water sources indicates risks that could occur in households if prior treatment is not carried out.

Of the seven HACCP steps, our study considered only four steps, which included formulation of a team, description of water system, identification of hazards, risks and events and control measures, and critical control limits. The water analysis was only done to support and provide evidence of the findings. However, the study only suggests control measures without an improvements' plan. The control measures suggested were 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 can be implemented. The contamination of water sources and the increased contamination in water kept in containers verify the available risks and support the need for pre-requisite and on-site 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, the 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 a systematic HACCP approach in South African households requires involvement of WSAs, environmental health practitioners, community leaders and household members to support and provide training; and 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 households. The study suggests that where mixed sources are used the provision of safe tap water provided by WSAs could not benefit the consumers. It could also confuse the entire process of risk assessment in households 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 cases of 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.

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## REFERENCES

Atusinguza, F. & Egbuna, C. K. 2012 A microbiological risk assessment of a private water supply in South East England: implication for future policy. *Journal of Life Science and Biomedicine* **3** (1), 40–51.

Bartram, J., Corrales, L., Davison, A., Deere, D., Drury, A., Gordon, B., Howard, G., Rinehold, A. & Stevens, M. 2009 *Water Safety Plan Manual: Step-By-Step Risk Management for Drinking-Water Suppliers*, World Health Organization Geneva, pp. 1–92 [online]. Available at: http://whqlibdoc.who.int/publications/2009/9789241562638_eng.pdf (accessed 20 July 2011).

Boone, C., Glick, P. & Sahn, D. 2011 Household water supply choice and time allocated to water collection: evidence from Madagascar. *Journal of Development Studies* **47**, 1826–1850.

Brown, J. M., Proum, S. & Sobsey, M. D. 2008 *Escherichia coli* in household drinking water and diarrheal disease risk: evidence from Cambodia. *Water Science and Technology* **58** (4), 757–763.

Clasen, T. F. 2009 Household water treatment in poor populations: is there enough evidence for scaling up now? *Environmental Science and Technology* **43** (4), 986–999.

Codex Alimentarius 1997 *General Principles of Food Hygiene. CAC/RCP 1-1969*, World Health Organization, Geneva, Switzerland, pp. 1–31. http://www.codexalimentarius.org/download/standard/CXP_001E.pdf (accessed 12 June 2014).

Davison, A., Deere, D. G., Stevens, M., Howard, G. & Bartram, J. 2006 *Water Safety Plan Manual*. World Health Organization, Geneva, Switzerland, pp. 3–34. http://www.who.int/water_sanitation_health/dwq/manual.pdf (accessed 20 July 2011).

Department of Water Affairs 1994 *Water Supply and Sanitation Policy*. Department of Water and Environmental Affairs, Pretoria, South Africa, pp. 1–20. http://www.dwaf.gov.za/Documents/Policies/WSSP.pdf (accessed 28 May 2009).

Department of Water Affairs 2009 *Drinking Water Quality Framework of South Africa: Minimum Requirements for Blue Drop Certification*. Department of Water and Environmental Affairs, Pretoria, South Africa, pp. 1–24.

Department of Water Affairs 2011 *Blue Drop Report 2011: South Africa Drinking Water Quality Management Performance*. Pretoria, South Africa, pp. 1–26.

Evans, B., Bartram, J., Hunter, P., Rhoderick Williams, A., Geere, J., Majuru, B., Bates, L., Fisher, M., Overbo, A. & Schimidt, W. P. 2013 *Public Health and Social Benefits of at-house Water Supplies*, pp. 3–35. Available at: www.r4d.dfid.gov.uk/…/water/61005 (accessed 15 November 2014).

Gelting, R. C. 2009 *Water Safety Plan: CDC's Role*. Environmental Health Services Branch, CDC, USA, pp. 1–2. http://www.cdc.gov/nceh/ehs/Docs/JEH/2009/Nov_09_Gelting.pdf (accessed 18 April 2013).

Gundry, S., Wright, J. & Conroy, R. 2004 Systematic review of the health outcomes related to household water quality in developing countries. *Journal of Water and Health* **2**, 1–3.

Howard, G. & Bartram, J. 2003 *Domestic Water Quantity, Service Level, and Health*. World Health Organization, Geneva, Switzerland, pp. 1–39. www.who.int/water_sanitation_health/diseases/WSH03.02.pdf (accessed 20 July 2009).

Hunter, P. R., Zmirou-Navier, D. & Hartemann, P. 2009 Estimating the impact on health of poor reliability of drinking water interventions in developing countries. *Science of the Total Environment* **407** (8), 2621–2624.

Hunter, P., Toro, G. I. R. & Minnigh, H. 2010 Impact on diarrhoeal illness of a community educational intervention to improve drinking water quality in rural communities in Puerto Rico. *BMC Public Health* **10** (11), 1–11.

Idexx 2001 *Colilert®-18 An Easy 18-Hour Test for Coliforms and E. coli*, pp. 1–2. https://www.idexx.com/water/products/colilert-18.html (accessed 18 January 2011).

La Freniere, J. 2008 The Burden of Fetching Water. MA thesis, Geography Department, University of Denver, Denver, CO, USA, pp. 4–21. http://scholar.google.co.za/scholar?q=LA+FRENIERRE%2C+J.+2008.+The+Burden+of+Fetching+Water.+Master+of+Arts%2C+University+of+Denver.&btnG=&hl=en&as_sdt=0%2C5&as_vis=1 (accessed 20 June 2013).

Majuru, B., Mokoena, M. M., Jagals, P. & Hunter, P. 2010 Health impact of small-community water supply reliability.

*International Journal of Hygiene and Environmental Health* **10** (1016), 1–5.

Mokoena, M. 2009 The Effect of Water-Supply Service Delivery on the Risk of Infection Posed by Water in Household Containers. MSc dissertation, University of Johannesburg library, Johannesburg, South Africa.

Mortimore, S. 2000 An example of some procedures used to assess HACCP systems within food manufacturing. *Food Control* **11**, 403–413.

Ozi-explorer 2010 GPS Mapping Software. http://www.oziexplorer.com/ (accessed 20 June 2011).

Peréz-Vida, C., Amézquita-Marroquin, C. & Torres-Lozada, P. 2013 Water safety plans: risk assessment for consumers in drinking water supply. *Ingeniera Y Competitividad* **15** (2), 237–251.

Peter, G. 2010 Impact of rural water projects on hygienic behaviour in Swaziland. *Physics and Chemistry of the Earth. Parts A/B/C* **35**, 772–779.

Pickering, A. J. & Davis, J. 2012 Freshwater availability and water fetching distance affect child health in sub-Saharan Africa. *Environmental Science and Technology* **46** (4), 2391–2397.

Potgieter, C., Mudau, L. & Maluleke, F. 2006 Microbiological quality of groundwater by sources used by rural communities in Limpopo Province, South Africa. *Water Science and Technology* **54** (11–12), 371–377.

Ricket, B., Schmoil, O., Renehold, A. & Barrenberg, E. 2014 *Water Safety Plan: A Field Guide to Improve Drinking Water Safety in Small Communities*. World Health Organization, Geneva, Switzerland, pp. 1–16.

Rosa, G. & Clase, T. 2010 Estimating the scope of household water treatment in low- and medium-income countries. *American Journal of Tropical Medicine and Hygiene* **82** (2), 289–300.

Rufener, S., Mäusezar, H. L. D., Mosler, H. & Weingartner, R. 2010 Quality of drinking water at source and point of consumption – drinking cup as a high potential recontamination risk: a field study in Bolivia. *Journal of Health Population and Nutrition* **28** (1), 34–41.

Shwe, V. D. T. 2010 A Randomised Trial of a Household Drinking Water Storage Intervention to Assess its Impact on Microbiological Water Quality and Diarrhoeal Diseases at Maela Temporary Shelter Tak Province, Thailand. Master dissertation, Chulongkom University, Bangkok, Thailand, pp. 1–87.

Sorlini, S., Pedrazzani, R., Pelazzini, D. & Collignarelli, M. C. 2013 Drinking water quality change from catchment to consumer in the rural community of Patar (Senegal). *Water Quality Exposure and Health* **5**, 75–83. DOI: 10.1007/s12403-013-0089-z.

South African Bureau of Standards 2011 *South African National Standard (SANS) 241: 2011. Drinking Water Standard*, 8th edn. Standards South Africa, Pretoria, South Africa, pp. 1–23.

Swierc, S., Page, D., Van Leuwen, J. & Dillion, P. 2005 *Preliminary Hazard Analysis and Critical Control Point Plan. CSIRO Land and Water Technical Report No. 20/05*. September 2005.

Wagah, G. G., Onyango, G. M. & Kibwage, J. K. 2010 Accessibility of water services in Kisumu municipality, Kenya. *Journal of Geography and Regional Planning* **3**, 114–125.

WHO 1997 *Hazard Analysis Critical Control Point (HACCP) System and Guidelines for its Application*. Annex to CAC/RCP 1-1969, Rev. 3. World Health Organization, Geneva, Switzerland. http://www.fao.org/docrep/005/y1579e/y1579e/y1579e03.htm (accessed 12 June, 2014).

WHO 2012 *Water Safety Planning for Small Community Water Supplies: Step by Step Risk Management Guidelines for Drinking Water Supplies in Small Communities*. World Health Organization, Geneva, Switzerland, pp. 1–66. Available at: http://apps.who.int/iris/bitstream/10665/75145/1/9789241548427_eng.pdf (accessed 25 November 2015).

WHO/UNICEF 2012 *Joint Monitoring Programme for Water and Sanitation. Report of WHO/UNICEF Entitled Progress on Sanitation and Drinking-Water – 2010*. Update, pp. 1–49. Available at: http://www.who.int (accessed 20 June 2013).

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