

Linking water quality monitoring and climate-resilient water safety planning in two urban drinking water utilities in Ethiopia

Harold van den Berg, Bettina Rickert, Seada Ibrahim, Kasa Bekure, Hailu Gichile, Seble Girma, Altaseb Azezew, Tadesse Zegeye Belayneh, Solomon Tadesse, Zeleke Teferi, Firehiwot Abera, Samson Girma, Tesfaye Legesse, Daniel Truneh, Gretta Lynch, Ingmar Janse and Ana Maria de Roda Husman

ABSTRACT

Unsafe drinking water is a recognized health threat in Ethiopia, and climate change, rapid population growth, urbanization and agricultural practices put intense pressure on availability and quality of water. Climate change-related health problems due to floods and waterborne diseases are increasing. With increasing insight into impacts of climate change and urbanization on water availability and quality and of required adaptations, a shift towards climate-resilient water safety planning was introduced into an Ethiopian strategy and guidance document to guarantee safe drinking water. Climate-resilient water safety planning was implemented in the urban water supplies of Addis Ababa and Adama, providing drinking water to 5 million and 500,000 people, respectively. Based on the risks identified with climate-resilient water safety planning, water quality monitoring can be optimized by prioritizing parameters and events which pose a higher risk for contaminating the drinking water. Water quality monitoring was improved at both drinking water utilities and at the Public Health Institute to provide relevant data used as input for climate-resilient water safety planning. By continuously linking water quality monitoring and climate-resilient water safety planning, utilization of information was optimized, and both approaches benefit from linking these activities.

Key words | drinking water, risk assessment, risk management, risk-based monitoring, water quality, water safety plans

Harold van den Berg (corresponding author)
Gretta Lynch
Ingmar Janse
Ana Maria de Roda Husman
 National Institute for Public Health and The Environment (RIVM),
 WHO Collaborating Centre for Risk Assessment of Pathogens in Food and Water,
 P.O. Box 1, 3721 MA Bilthoven, The Netherlands
 E-mail: harold.van.den.berg@rivm.nl

Bettina Rickert
 German Environment Agency (UBA),
 WHO Collaborating Centre for Research on Drinking Water Hygiene,
 Schichauweg 58, 12307 Berlin, Germany

Seada Ibrahim
Kasa Bekure
Hailu Gichile
 Adama Water Supply and Sewerage Enterprise,
 Geda Kebele,
 Kebele 12, Adama, Ethiopia

Seble Girma
Altaseb Azezew
Tadesse Zegeye Belayneh
Solomon Tadesse
Zeleke Teferi
 Addis Ababa Water and Sewerage Authority,
 P.O. Box 1505, 1110 Addis Ababa, Ethiopia

Firehiwot Abera
Samson Girma
Tesfaye Legesse
 Ethiopian Public Health Institute,
 1242 Patriot Street, Addis Ababa, Ethiopia

Daniel Truneh
 Vitens Evides International,
 Reactorweg 47, 3528 AD, Utrecht, The Netherlands

Ana Maria de Roda Husman
 Institute for Risk Assessment Sciences,
 University of Utrecht,
 Utrecht, the Netherlands

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INTRODUCTION

Safe and readily available drinking water is important for public health and was declared a UN human right in 2010 (UN 2010). In 2015, 2.1 billion people still lacked safely managed drinking water services, of whom, 582 million people abstracted water from non-improved and unprotected sources worldwide (WHO and UNICEF 2017). Drinking unsafe water may cause exposure to pathogens, which can result in waterborne diseases such as cholera, gastroenteritis and hepatitis E (Howard & Bartram 2003). Although considerable improvements have been achieved, poor drinking water quality still is a recognized health threat in Ethiopia since a considerable burden of disease originates from unsafe water. In Ethiopia, the mortality rate attributed to unsafe water, sanitation and hygiene services is 43.7 per 100,000 persons (WHO 2018), and the average Ethiopian child suffers five to 12 diarrheal episodes yearly as a result of poor drinking water and poor environmental sanitation (MoH 2011). An outbreak of acute watery diarrhoea was reported in nine regions of Ethiopia between January and December 2017 (WHO Afro 2018). Another outbreak with 1,117 suspected cases of hepatitis E and 21 deaths was reported among refugees residing in the Gambella region from April 2014 to January 2015 (Browne *et al.* 2015). Adane *et al.* (2017) concluded that acute diarrhoea among children under five years of age in slums of Addis Ababa can be reduced by continuously available piped water supplies and education of urban caregivers.

The importance of water, sanitation and hygiene for development, poverty reduction and health had previously been recognized in, among others, the United Nations Millennium Declaration and is reflected in Sustainable Development Goal (SDG) 6.1 of the UN declaration *Transforming our world: the 2030 Agenda for Sustainable Development* (UNGA 2015), which calls for achieving universal and equitable access to safe and affordable drinking water for all by 2030. The UNICEF/WHO Joint Monitoring Programme update and SDG Baseline report on drinking water, sanitation and hygiene (WHO and UNICEF 2017) showed that in Ethiopia, the proportion of the population with access to an improved water supply was increased from 58% to 75% between 2000 and 2015, with an increase

of the population with access to safely managed supplies from 5% to 11% in the same timeframe (WHO and UNICEF 2017).

The frequency and intensity of extreme weather events with possible consequences for drinking water safety are increasing due to climate change (Delpla *et al.* 2009; Seneviratne 2012). In the context of climate change, a degradation trend of drinking water quality leads to an increase of at-risk situations leading to potential health impacts (Delpla *et al.* 2009). Eastern Africa is one of the most vulnerable regions with respect to the impacts of climate change (Samson *et al.* 2011), and in Ethiopia, climate change-related health problems, such as mortality and morbidity due to droughts, floods and waterborne diseases are increasing (Simane *et al.* 2016). The effects of climate change will continue to magnify without the right adaptation and mitigation measures (Simane *et al.* 2016). Besides climate change, rapid population growth, urbanization and inappropriate farming put intense pressure on the available water (Simane *et al.* 2016).

The World Health Organization (WHO) established a 'Framework for Safe Drinking-water' which encompasses setting health-based targets, a risk assessment and risk management approach and a system of independent surveillance (WHO 2011). A so-called water safety plan (WSP) is the recommended risk assessment and risk management approach, including all steps in water supply from catchment to consumer. In 2017, the WSP approach was extended by also identifying and managing climate-related impacts from catchment to consumer (WHO 2017). In 2015, the Federal Ministry of Water, Irrigation and Energy published guidelines for CR-WSP Implementation for Urban Utility Managed Piped Drinking Water Supplies (MoWIE 2015). The steps for implementing CR-WSP are shown in Figure 1.

As part of the WSP approach, different monitoring should be applied to provide information on drinking water operations and drinking water quality:

- testing and monitoring of the quality of drinking water (verification monitoring) and source water used for drinking water production;

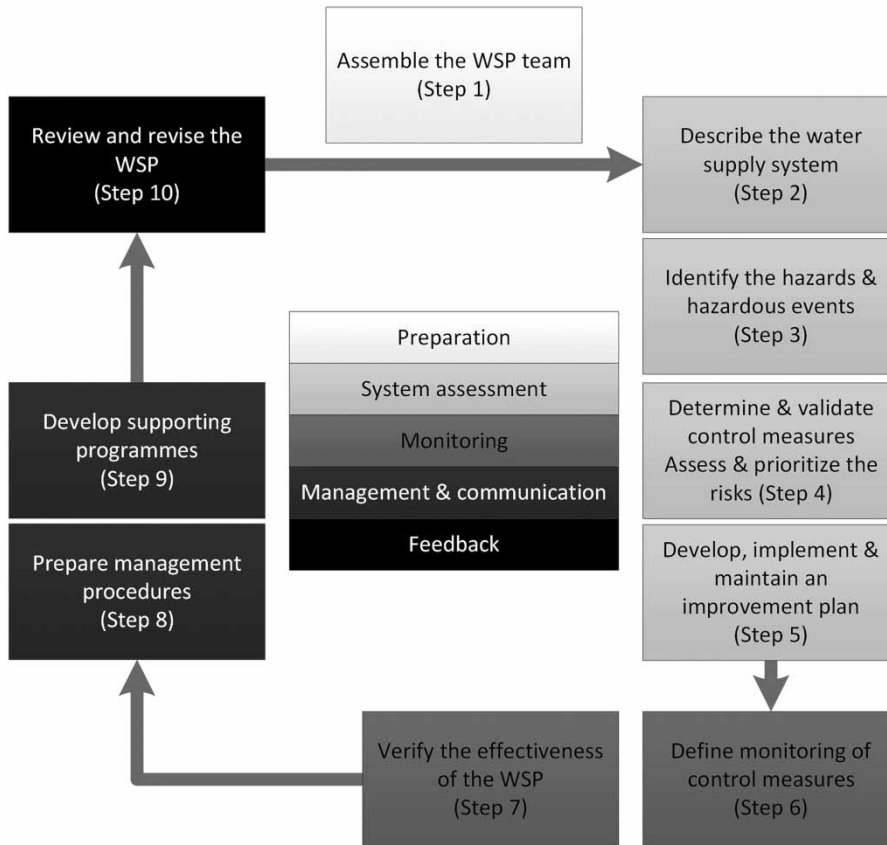


Figure 1 | Steps of CR-WSP (adapted from MOWIE 2015).

- monitoring to demonstrate the performance of control measures under normal and exceptional circumstances (validation monitoring);
- monitoring operational parameters showing whether the processes in drinking water supplies are operated safely (operational monitoring).

These types of monitoring are key elements that contribute to drinking water safety, and thereby protecting public health (WHO and IWA 2009).

In Ethiopia, the physical, chemical and bacteriological requirements for drinking water are described in the Compulsory Ethiopian Standard for Drinking Water Specification (Ethiopian Standards Agency 2013). Ethiopian drinking water utilities are mandated to comply with the requirements of these standards for drinking water supply. The 'Framework for Safe Drinking-water' prescribes that surveillance should be carried out by an independent agency. The established regulatory arm of the Federal

Ministry of Health which is Food, Medicine and Health Care Administration and Control has an Inspection and Surveillance directorate responsible for regulating water quality monitoring (WQM) (MoH 2014).

The project Source to Tap and Back (S2TAB) started in 2013 in Ethiopia. The goals of the project were to establish:

- a stakeholder dialogue and capacity development approach for improved financial and environmental sustainability of drinking water services;
- improved control of wastewater discharges in the catchments;
- water resource protection;
- measures to reduce sedimentation in the catchment reservoirs;
- improved water supply and service delivery in two drinking water supplies;
- increased access to improved sanitation;
- reduction of non-revenue water to reduce water loss.

Vitens Evides International (VEI) coordinated this Dutch–Ethiopian project, which involved four Ethiopian and five Dutch partners: Addis Ababa Water and Sewerage Authority (AAWSA); Adama Water Supply and Sewerage Enterprise (AWSSE); Oromia Water Mineral and Energy Bureau; Ethiopian Public Health Institute (EPHI); Vitens Evides International (VEI); Dutch Water Authority Vallei en Veluwe; Dutch Water Authority Zuiderzeeland; MetaMeta; and Dutch National Institute for Public Health and the Environment (RIVM). For the implementation of CR-WSP, the German Environment Agency (UBA) was subcontracted.

In this study, we focused on the part of the project S2TAB to improve water supply and service delivery. The objectives of this part of the project were to implement CR-WSPs in the urban water supplies of Addis Ababa and Adama and to strengthen drinking WQM at the laboratories of both drinking water utilities and the EPHI. The study aims at showing how a strong link was established between CR-WSP and WQM and how these complementary approaches benefit from joined implementation to promote sustainable provision of safe drinking water in urban utilities.

MATERIAL AND METHODS

Drinking water utilities and laboratories

The AWSSE is a company responsible for water and sewerage services in Adama. AWSSE provides water supply service to approximately 500,000 people. The company was established under the municipality of Adama in 1930 and under the Oromia Water Mines and Energy Bureau. AWSSE is governed by a board consisting of representatives from several government offices. AWSSE has one drinking water treatment plant, at the site of which the laboratory for testing drinking water is also located.

The Addis Ababa Water and Sewerage Authority (AAWSA) is responsible for providing water and sewerage services to Addis Ababa, the capital of Ethiopia. The service area (over five million people) is limited to the boundaries of Addis Ababa city administration. AAWSA was established in 1971 and is governed by a board consisting of representatives from several government agencies. AAWSA has two drinking water treatment plants located in Legedadi and

Gefersa. The laboratory for testing drinking water is located at the head office of AAWSA.

EPHI, as the technical body of the Federal Ministry of Health, is focusing on priority disease research and strengthening the national public health laboratory services in the country. This institute is located in Addis Ababa and conducts research on the causes and spread of diseases on food and water safety issues, and thereby supports activities for the improvement of health in the country. EPHI has knowledge and expertise on water quality testing, such as physico-chemical and microbiological analyses. Previously, EPHI conducted a rapid assessment of drinking water quality (Tadesse *et al.* 2010), and carried out several water quality studies in Ethiopia. Some objectives of EPHI regarding drinking water are monitoring the quality and safety of water and development of associated guidelines.

Baseline study

At the start of the project S2TAB, a baseline study was conducted to identify the awareness of WSP at both drinking water utilities and the level of WQM at the drinking water utilities and EPHI. During the baseline study, both drinking water utilities and EPHI were visited twice in 2013 by a team from RIVM, UBA, VEI and EPHI. During the baseline study, information was gathered on the roles and responsibilities of the organizations. Furthermore, the need for implementing WSPs and improving WQM was identified by interviewing staff from the water supplies and EPHI.

Implementation of climate-resilient water safety plans

Within the project, implementation of WSPs started in 2014 in both drinking water utilities, following the Water Safety Manual (WHO and IWA 2009). Within the implementation period, the WSP approach was amended to integrate a focus on climate resilience (Rickert *et al.* 2019) according to the steps of CR-WSP, as described in the Ethiopian Guidelines for Urban Utility Managed Piped Drinking Water Supplies (MoWIE 2015) (see Figure 1).

External experts of the WHO Collaborating Centres at UBA and RIVM led the implementation of CR-WSP and supported the teams within the water utilities. As a local partner, EPHI joined the training for the implementation

of CR-WSP to gain experience for future scaling up. For the implementation, a step-by-step approach was followed during the implementation period 2014–2018 with regular visits by the external experts. During these visits, nine training and consultation meetings were provided to facilitate WSP implementation within the teams of the utilities, and two annual workshops were conducted to exchange experiences, challenges and success factors between the drinking water utilities.

Strengthening WQM

At the national level, WQM was strengthened by training EPHI laboratory staff in pathogen detection, such as enterovirus, *Campylobacter* and *Cryptosporidium* in water. It is not mandatory to measure these pathogens in drinking water (Ethiopian Standards Agency 2013), but information of the presence of these pathogens in source waters used for the production of drinking water is of added value. The detection methods for these pathogens were based on molecular techniques. Training was conducted in a series of four training sessions during 2013–2018 to prepare trainees for organizing WQM and sharing knowledge with drinking water laboratories.

WQM was strengthened at the drinking water laboratories at both utilities by improving the laboratory infrastructure and providing necessary equipment. EPHI supported in purchasing materials, media and equipment from the local market. One training session on WQM for both water utilities was organized by EPHI in 2015. This session focused on the detection of core parameters, such as pH, temperature, turbidity, free chlorine and *Escherichia coli*. Furthermore, training was given by RIVM at both laboratories to introduce and implement new methods, both for physico-chemical and microbial testing, and to update existing procedures.

RESULTS

Baseline study

The baseline study identified that both drinking water utilities and EPHI had no or only limited knowledge on WSP.

WQM was in place at the laboratories of both drinking water utilities, and staff were well trained in the methods used. Nevertheless, there was a need to improve the methods and to test for additional parameters to show compliance with the national standards. The laboratories were differently equipped and both laboratories were in need of upgrading. At both drinking water utilities, monitoring data were collected and stored in logbooks, but data were not available electronically. Independence surveillance is limited to date.

Although EPHI performs several analyses for WQM, the baseline study found that WQM at EPHI should be improved by detection of additional parameters, such as heavy metals, pesticides and pathogenic bacteria, viruses and parasites. Furthermore, applying molecular techniques for the detection of pathogens was identified as an advantageous improvement for the water quality testing at EPHI.

Kick-off workshops

Before starting the implementation of CR-WSP and improvement of WQM, a 2-day workshop was held at each of the drinking water utilities in December 2014. The goal of these kick-off workshops was to create enthusiasm and support for the implementation. During the workshops, information was provided by RIVM and UBA on water-borne infectious diseases, WQM, CR-WSP and how CR-WSP and WQM complement each other. In total, 14 persons from the Adama water supply and 35 persons from the Addis Ababa water supply participated. Four persons from EPHI participated at both workshops to be able to support the further implementation of CR-WSP and WQM. For each water utility, a team was established for conducting the implementation of the CR-WSP and another team for improving WQM. In both utilities, there was an overlap of staff between the teams to create synergies between WQM and CR-WSP. Furthermore, each team of the water utilities had an EPHI representative assigned to support the activities.

Implementation of climate-resilient water safety plans

Nine training and consultation meetings on the steps of CR-WSPs were provided by UBA and RIVM from December

2014–January 2018 to both water utilities. The training visits were used to facilitate and discuss CR-WSP implementation with the teams.

As the first task for the CR-WSP teams, a comprehensive system description was developed at each of the water utilities, based on all relevant existing documentation, and additional information was collected if needed. Based on this system description, both teams identified all hazardous events which could occur in their water supply system, potentially introducing hazards for public health. For this step, a generic list of hazardous events was used and adapted to reflect the situation in the respective water supplies (Rickert & Van den Berg 2018). The teams also considered hazardous events related to climate conditions such as storm events, heavy rainfall or extended drought periods.

For confirmation of the system description and hazardous events, field visits were conducted by the teams. During these field visits, new hazardous events were identified and documented. One example of such a new hazardous event was the identification of broken vent screens at storage reservoirs which may lead to contamination of the water through ingress of insects.

For all identified hazardous events, the teams investigated whether control measures were already in place. For these existing control measures, the teams validated their effectiveness by providing evidence (e.g., monitoring data, literature data or reports of visual inspections). Afterwards, risks were assessed based on the likelihood and severity of each of the hazardous events, also taking into account the presence and effectiveness of the existing control measures.

Both teams agreed on definitions for the likelihood categories ('unlikely', 'possible' and 'most likely') and severity categories ('no or minor impact', 'moderate impact' and 'major impact'), as well as for the risk categories ('low', 'medium' and 'high' risk) to be applied for the risk assessment, which were based on the definitions included in the Ethiopian guidance for urban utilities (MoWIE 2015). These definitions and the risk matrix were translated into Amharic language.

Based on a table documenting all possible hazardous events and resulting risks for each of the utilities, the teams drafted improvement plans for risks identified as being high or medium, and gave an overview of all proposed actions to reduce the risks. The resulting improvement plans

triggered both drinking water utilities to initiate some improvements immediately, such as:

- creating awareness of working hygienically and training chemical flow workers and laboratory technicians;
- developing hygiene leaflets for drinking water production areas to create awareness of workers at the utilities and reservoirs, as well as of consumers collecting drinking water at public taps;
- conducting training on maintenance of plumber technicians and supervisors;
- updating the standard operating procedure (SOP) for sand filtration;
- preparing and updating the operation manuals at the treatment plants.

Within the project, a budget was allocated for improvements achievable in a short period and at low cost (so-called 'quick wins'), based on the improvement plans. Both teams selected some improvements from their respective improvement plans and presented these to the higher management. The following quick wins were initiated within the project:

- relocating effluent discharge of dry-sludge bed further downstream;
- cleaning of dry-sludge bed;
- building fences around four public taps;
- renewing existing vent screens at storage reservoirs in the distribution system;
- installing manhole covers;
- installing chlorine mixers in reservoirs;
- removing plants around a storage reservoir.

In addition to the quick wins and the achievements made by the drinking water utilities, further improvements were carried out within other parts of the project. Examples include:

- planting 12,000 indigenous trees in the catchment to reduce the amount of run-off and erosion (coordinated by MetaMeta);
- building 24 check dams in the catchments to reduce hazards from run-off entering the source water during rainfall (coordinated by MetaMeta and VEI);
- improving sanitation in the catchment by construction of toilets in schools and at market places (coordinated by MetaMeta and VEI).

Operational monitoring shows whether the control measures in place were working effectively. Based on the previously existing practices at the water utilities, both teams updated operational monitoring plans, including documentation of all activities already in place. Some examples of operational monitoring activities were:

- checking the infrastructure of a storage reservoir on a daily basis;
- controlling water in the clarifier (e.g., for algae) by visual inspection on a daily basis;
- measuring the filter depth of the sand filters every two months;
- measuring the turbidity at the treatment effluent twice per day.

The teams also documented which actions should be undertaken when the monitored parameters exceed their critical limits as specified in the operational monitoring plan.

At both drinking water utilities, the effectiveness of WSP activities was verified using auditing and compliance monitoring, as well as information on customer satisfaction. Information gathered by WQM was applied to check whether drinking water complied with drinking water quality standards. Outcomes were fed into the CR-WSP to analyse effectiveness of implemented measures and provide information on relevant hazards.

The emergency plans of both utilities were updated within the project. These include information on who should be contacted in case of an emergency, and describe several concrete emergency situations such as flooding, power disruption and bursting of chlorine gas storage cylinders. The Addis Ababa team developed separate emergency response plans for each of the utility's branch offices responsible for a specific distribution area, and documented SOPs in one book with instructions (operational manual for the production location and analysis book for the laboratory), rather than short documents to take into the field, laboratory or to the treatment plant. This team extracted the necessary information for SOPs for plumbers (branch officers) and operators (treatment plant) from the operational manual, to facilitate regular application when needed. In Adama, work instructions were available and the team updated the available work instructions and prepared additional SOPs.

At both water utilities, several supporting programmes existed, such as creating awareness on pollution of source water among consumers and the population in the catchment (farmers and industries), providing information on websites, research, training and maintenance. The project increased the awareness raising:

- by sharing the utilities' concerns about activities in the catchment, threatening the production of drinking water. Concerns were discussed with stakeholders, such as the water resource protection team established within the project;
- by preparing leaflets for public taps to provide information to the consumers how to safely collect and store water in a container and how to avoid contamination of the area around the public taps. The leaflets were provided in Amharic and in Oromian languages;
- among stakeholders, excluding the water utilities, for the possible hazards and hazardous events for the production of safe drinking water, by the utilities joining a stakeholder platform established within the project, coordinated by the Dutch Water Authorities, MetaMeta and VEI;
- among people living in the catchment on improved sanitation coordinated by MetaMeta;
- with industries on emission reduction, based on data gathered within the project by the Dutch Water Authorities, MetaMeta and EPHI;
- by preparing leaflets for drinking water production areas and at storage reservoirs in the distribution network to provide information to the workers to work hygienically. The leaflets were produced in Amharic and in Oromian languages.

Within the project S2TAB, additional training was conducted to improve the skills of employees, plumbers, laboratory staff and chemical workers.

The project provided a platform for exchange between stakeholders such as AAWSA, AWSSE, Oromia Water, Mines and Energy Bureau, basin authorities, environmental protection entities including practitioners, water resource managers, EPHI and climate scientists from Addis Ababa University to support decision-making based on knowledge of the complex water security trade-offs needed for

resilience through providing a platform for a multi-stakeholder process.

The CR-WSP teams developed a schedule for regularly revising and reviewing their CR-WSPs. Furthermore, both utilities planned to conduct a peer view between the two drinking water utilities to learn from each other.

Strengthening WQM

Within the project, WQM was strengthened at both utilities by harmonizing methods according to the Ethiopian drinking water legislation and by adding parameters based on possible risks identified from CR-WSP.

Both utilities used different methods for the detection of the faecal indicator *E. coli*, and rarely used membrane filtration for enumeration. Therefore, membrane filtration was introduced or improved, respectively, to harmonize the methods at both laboratories. In Addis Ababa, chemical analyses were already conducted regularly on samples, however in Adama, physico-chemical analyses such as testing for turbidity, conductivity, fluoride, manganese, free chlorine and iron needed to be improved. At both laboratories, there was an interest in improving good laboratory practices and data analysis. Based on the needs' assessment, equipment, media and custom-made training sessions were provided and the laboratories' infrastructure was upgraded.

In 2015, EPHI organized a centralized training that focused on basic WQM, including sampling, physico-chemical analyses (temperature, pH, turbidity and free residual chlorine) and microbiological analyses (*E. coli* and coliforms) using membrane filtration techniques. The custom-made training sessions followed up the centralized training and facilitated the implementation of the methods for basic WQM at both laboratories. In Adama, follow-up sessions were conducted for implementing basic WQM using the supplied materials and trained methods. The basic WQM was extended by chemical analyses for 11 new parameters, such as fluoride, nitrate, manganese and phosphate within an additional training. In Addis Ababa, sessions were conducted that focused on strengthening the current WQM programme and included both chemical and microbial WQM techniques, good laboratory practice, documentation and data analysis. At the laboratories of AAWSA and AWSSE, the staff developed 20 and 14 SOPs, respectively, for routine laboratory

work and sampling. In between the training sessions, RIVM and EPHI followed up with regular visits to identify challenges and needs regarding WQM.

At both drinking water utilities, the laboratories were upgraded with the logistical support of VEI. In Addis Ababa, there were three different laboratories for chemical analysis, microbiological analysis and general laboratory work. These laboratories were outdated and were therefore renovated within the project. AWSSE had one laboratory for WQM, which was upgraded through renovation activities using the utility's own budget. Within the project, expansion of the laboratory with another room to separate chemical and microbiological analyses was initiated.

At EPHI, WQM was strengthened at the national level by introducing pathogen detection methods for enteroviruses, *Cryptosporidium*, *Giardia* and *Campylobacter* spp. and improving the detection of *E. coli* as faecal indicator using membrane filtration in combination with chromogenic media. During annual practical and theoretical training sessions by RIVM during the timeframe 2013–2018, participants became familiar with these techniques. At one of these training sessions, the drinking water utilities participated to create more awareness on pathogen (instead of indicator) detection. In the future, EPHI may disseminate these methods to different (regional) laboratories. Together with EPHI's department of food and water microbiology, a monitoring plan was developed and carried out for the detection of faecal contamination and pathogens in source waters in and around Addis Ababa. The information from this study may be used as an input for future CR-WSP revisions. Additional research, supported within S2TAB and conducted by EPHI, will provide information for the drinking water utilities, such as efficacy of water treatment during extreme weather events and the presence of antibiotic-resistant bacteria in the source waters used for drinking water production.

Linking water safety planning and WQM

The project linked CR-WSP and WQM activities from the start. To guarantee that information from the laboratory reached the teams involved in the implementation of CR-WSP and vice versa, one or two persons from the laboratory were a member of the CR-WSP team. In this way, risks

identified during the implementation of CR-WSP or requests for additional information on water quality could be addressed directly to the laboratory.

During the regular visits by the external experts, CR-WSP and WQM training sessions were held back to back in order to stress the importance of linking these components. With combined sessions during the visits, information was shared between both teams of each water utility to increase awareness for CR-WSP and WQM. Three annual workshops were conducted to facilitate exchange of experiences, challenges and success factors between the drinking water utilities and EPHI.

As part of the CR-WSP, both drinking water laboratories reviewed and revised the existing WQM plan in place, also taking into account hazardous events relevant in their respective utilities. This resulted in adding parameters for future monitoring in raw water, such as fluoride in Adama and *Cryptosporidium* and *Giardia* in Addis Ababa. To harmonize management procedures, the WQM staff developed, in line with CR-WSP, SOPs for sampling, transport, chemical and microbiological analyses.

DISCUSSION

Traditionally, both drinking water utilities addressed problems in the drinking water system, such as pipe breaks or customer complaints, mainly when they occurred. The WSP framework, however, is designed to proactively prevent hazards or hazardous events (WHO and IWA 2009).

CR-WSPs were successfully implemented at both drinking water utilities. As part of the CR-WSP approach, WQM is applied to provide information on the operation of drinking water treatment processes and drinking water quality. One of the challenges for the implementation of WSP is a lack of laboratory facilities and methods for WQM (WHO and IWA 2009; Rahman & Paul 2011). Therefore, facilities and methods on WQM were also strengthened.

Challenges identified during implementation

One of the challenges during this process was the high turnover of staff, particularly at one of the utilities. This resulted in frequent changes in the WSP teams, which had a negative

effect on sustainable implementation. During the project, organizing team meetings was a challenge because of absence of team members due to other responsibilities. The attitude of management has been described to drive or hinder effective WSP implementation in the East-Africa region as they prioritize the work of the staff (Parker & Summerill 2013), and was also observed in the subject project implementation. This has been recognized for other regions as well, such as the Asian Pacific region (Kumpel *et al.* 2016), which may be caused by insufficiently supporting management. Moreover, the role and motivation of the team leader is crucial, and at both utilities the team leader changed during the project. The replaced team leaders had significantly different ideas on implementing CR-WSPs, such as composition of the teams, regular meetings and priority areas. Long time periods between project visits due to several factors reduced motivation and commitment to continue.

Challenges that affected the WSP and WQM activities were comparable to challenges as described by Peletz *et al.* (2016), such as procurement processes that were delayed due to the requirement of multiple bids, lack of a provider in the country and availability of a vehicle for sampling of the distribution network. At the beginning of the project, laboratories appeared to have had equipment obtained from previous projects. Based on this, the project management decided not to invest in similar products, but to pay more attention to training and application. This advocates for a thorough needs' assessment to identify existing materials and needs of the laboratory before investments, as was done in this project.

Lack of support from other stakeholders, particularly on catchment management is a barrier for CR-WSP implementation (Parker & Summerill 2013). Management of water resources is essential to achieve sustainability of water services. This is impeded when there is a lack of coordination such as between the urban service delivery operator and stakeholder acting in rural catchment areas. In these situations, instead of establishing dialogue and collaboration, the priority has often been to develop technical capacity for managing the engineered water supply infrastructure. Addressing climate resilience requires new skill sets and collaborations to consider the catchment, the management of the land and the other water users, as well as how all of

these aspects are expected to change. Delivering climate-resilient water supply services to the growing, developing populations of Addis Ababa and Adama is a major coordination challenge to promote inter-sectoral cooperation.

Benefits identified during implementation

Kumpel *et al.* (2018) described an assessment scheme for showing the impact of implementing WSP based on performance indicators, including infrastructure improvements, increased financial support, changes in operations and management practices, non-revenue water, water quality testing and monitoring consumer satisfaction. According to the WHO and IWA (2017), the main benefits of WSP implementation are:

- improved system management;
- increased awareness, knowledge and understanding among staff;
- increased promotion and knowledge sharing;
- improved communication and collaboration;
- improved water quality;
- improved monitoring;
- increased capacity building and training;
- improved record keeping;
- improved managerial and operational procedures.

This shows that most benefits are related to performance indicators which can not easily be numerically measured, with the exception of improved water quality. One challenge in documenting improvement is that the water supplies for which data are available at the outset tend to be higher-capacity supplies with high indicator levels at baseline already, whereas other supplies with more room for improvement tend to lack baseline data, making it challenging to document improvement (Kumpel *et al.* 2018). Although at the beginning of the project, no clear performance indicators were set to measure the impact of WSP implementation, most of the above-mentioned benefits of WSP implementation could be confirmed, including the linkage to improved monitoring activities. Both water utilities reported that implementation of CR-WSPs resulted in a more proactive attitude and approach of managing the water supply, thereby preventing health hazards. Adama reported an improved reputation with the consumers.

Prioritizing risks was assessed by the teams to be a solid basis for action and for attracting funding for improvements. Recently, positive customer feedback was received for action taken in the case of leakages or complaints for both water utilities. During the implementation of CR-WSP, most time was spent on the first four steps of CR-WSP. This was also described by Sutherland & Payden (2017) for South-East Asia. A budget was allocated for quick wins, which were executed two to three years after the beginning of project implementation. It might be more motivating to have quick wins at an earlier stage, to motivate the team and management. These quick wins demonstrated the positive effects of the CR-WSP approach using the risk assessment as a basis.

Compared to the situation prior to the project, the laboratory staff was more motivated, because of investments that were done in the first part of the project, such as purchasing of materials and implementation of methods. The laboratory staff did not change frequently and this had a positive influence on the motivation of WQM implementation. The project introduced monitoring of additional parameters, or monitoring existing parameters more frequently, to extend information on compliance with the national standards (Ethiopian Standards Agency 2013).

Although over the past decades monitoring of drinking water as a final product has been the norm globally to determine whether drinking water is free from contamination, it has become clear that this is often too little and too late. Final product monitoring only provides information on a limited amount of water sampled at a given time, a limited number of parameters, and results are only available after possibly contaminated water has been consumed. Introduction of a risk management approach, such as CR-WSP, provides more focus on safely managing the processes to guarantee safe drinking water. WQM is important to verify whether the CR-WSP is effective. Due to introducing or improving methods for WQM, the laboratories were able to provide information on source water quality, drinking water operations and drinking water quality that could inform CR-WSP.

Both CR-WSP and WQM benefit from strengthening the link between them: better risk management decisions could be made based on WQM data, whereas WQM could be adapted based on the input from CR-WSP. Another benefit

was that there was better understanding on the activities and needs from different departments. For instance, staff in the distribution network did not understand why results of *E. coli* were given only after 2 to 3 days. By sharing the need for rapid results in the distribution network and the supply information on the methodology for detection, mutual understanding was created. Through consultation with the laboratories, an alternative was found to provide reliable results within a shorter time period. This example showed that communication between laboratory staff and CR-WSP is important. During the project, the importance of linking CR-WSP and WQM was stressed in annual meetings and during regular visits.

A risk-based WQM approach is important for independent surveillance, particularly when limited funding is available to optimally detect evidence for the existence of risks for public health. Several organizations, such as the WHO and United Nations Economic Commission for Europe, support cost-effective and risk-based drinking water quality surveillance approaches (WHO 2015). During CR-WSP implementation, several risks were identified that affected water quality from source to tap. These risks were communicated to the WQM team for adapting existing WQM to a more risk-based approach. By initiating trend analyses in the water quality, information will be gathered on the presence of several parameters over the years, and will also inform about seasonal fluctuations. As a result, identified trends or fluctuations can support preventing future exceedances of the threshold values. Climate change can have negative effects on the water quality of source water and drinking water (Delpla *et al.* 2009), and this project initiated research on the effects of extreme weather events on source water quality and drinking water operations to support risk-based WQM and CR-WSP. Not only climate change, but also other developments, such as urbanization, population growth, illegal settlements or industrialization, might have a negative impact on the source water quality and introduce or exacerbate risks and should therefore be considered in CR-WSPs, and may require adaptation of WQM.

To increase the sustainability and the visibility of the work of the CR-WSP and WQM teams at the drinking water utilities, participation in platforms is crucial to address water safety in the catchment and to be supported by external stakeholders. Within this project, collaboration between

both drinking water utilities and the government (EPHI) was established, in order to share experiences and address challenges on both CR-WSP and WQM. Stakeholders who participated in the training sessions and who supported the implementation of CR-WSP and improvement of WQM at both drinking water utilities may serve as (national) focal points for further CR-WSP implementation and improving WQM in Ethiopia in the future. Small and medium water supplies could benefit from the knowledge and expertise on CR-WSP implementation gained within this project to implement CR-WSP in conjunction with WQM in their supplies. At the end of 2018, four members from the CR-WSP teams were involved to support the implementation of CR-WSP in four small towns in Oromia and may continue with other small towns.

CONCLUSIONS

Continuously linking WQM and CR-WSP showed to be beneficial for both project parts, as knowledge was constantly shared between different experts within the water utilities and the use of this obtained information could be optimized. At both drinking water utilities, CR-WSPs, as described in the Ethiopian Guidelines for Urban Utility Managed Piped Drinking Water Supplies (MoWIE 2015), were implemented, and WQM was strengthened, including compliance monitoring and operational monitoring at the utilities and source WQM at EPHI. This supports the benefit described in the literature, that one of the main benefits of WSP implementation is improved water quality testing and monitoring consumer satisfaction. Monitoring data provided evidence that was used for risk management decisions as part of CR-WSP and identified risks from CR-WSP were used to adapt WQM in a way that data are more meaningful. Such a risk-based WQM approach is better suited to anticipate environmental variations caused by climate change, urbanization, population development or seasonal fluctuations. The improvement of WQM and introduction of CR-WSP in one project at the same time supported adaptation of WQM approaches through introducing additional parameters and new methods. If the risk assessment of a CR-WSP identifies the need to analyse for additional parameters in order to verify water safety, it is very advantageous if funds have

already been allocated for improving and extending WQM, as was the case in this project.

CR-WSP and WQM are iterative processes, indicating that drinking water utilities need to continue with these approaches also after project completion for sustainable application.

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