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Including aspects of climate change into water safety planning: Literature review of global experience and case studies from Ethiopian urban supplies

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ABSTRACT

In recent years, the water safety plan approach has been extended towards climate-resilient water safety planning. This happened in response to increasing insight into impacts of climate on drinking-water and required adaptation to anticipated climate change. Literature was reviewed for published guidance and case examples, documenting how to consider climate in water safety planning to support future uptake. Climate-resilient water safety plans were piloted within a project in the water supplies of Addis Ababa and Adama, Ethiopia.

Case examples have been published in four of six WHO regions with a focus on urban supplies. Integration of climate aspects focused mostly on the steps of establishing the team, system description, hazard analysis and risk assessment, improvement planning and development of management procedures. While the traditional framework focuses on drinking-water quality, considering climate change augments aspects of water quantity. Therefore, other factors affecting water quantity such as population development and demand of other sectors need to be considered as well. Local climate information and tools should be employed as a significant success factor for future uptake. Such information should be incorporated as it becomes available, and may – depending on the setting – be incrementally integrated into existing water safety plans or used to develop new ones.

1. Introduction

Safe drinking-water is acknowledged as a basic human right (United Nations UN General Assembly, 2010) and should therefore be available for everyone. In order to achieve safety of drinking-water, the World Health Organization (WHO) recommends in its Guidelines for Drinking-Water Quality (WHO, 2004, 2017c) a risk assessment and risk management approach including all steps in water supply from catchment to consumer called water safety plans (WSP). Climate change, together with population growth, increasing urbanisation and increased water demand, is expected to present an additional burden to water supplies (WHO, 2017a). Increasing insight into impacts of climate change and required adaptation initiated some shift towards climate resilient water safety planning (CR-WSP). This extends the traditional WSP framework by additionally identifying and managing climate-related impacts on water supply systems to strengthen resilience (WHO, 2017a).

Target 6.1 of the Sustainable Development Goals calls for equitable access to safe and affordable drinking-water for all by 2030 (United Nations UN General Assembly, 2015), and while baseline data showed that 71% of the global population were served by safely managed water services, this was in sub-Saharan Africa only the case for 24% of the population (WHO, 2017c,d). 829,000 people are estimated to have died from diarrhoea related to water, sanitation, and hygiene in 2016 (WHO, 2019). Yet, diarrhoea is largely preventable, and the deaths of 361,000 children aged under 5 years could be avoided each year if these risk factors were addressed (Prüss-Ustün et al., 2014).

Climate change is expected to alter the frequency and severity of extreme weather events with possible consequences for the safety of drinking-water supplies (WHO, 2017a). Examples of climate related events which have a negative effect on the production of drinking-water are increased surface run-off due to heavy rainfall that contaminates sources for drinking water production, increased concentration of

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pollutants in source waters due to extreme drought periods, formation of crevices in dry soil leading to rapid pathways for contaminants, and more favourable growth conditions for pathogens due to increased water temperatures. Weather events, especially dry periods followed by heavy rainfall, have been shown to be associated with acute gastroenteritis in France and Spain (Setty et al., 2018). While water suppliers are already dealing with climate related events such as heavy rainfall or droughts during their normal operation, not all of them have considered how to adapt to anticipated future changes in climate, or have not done so in a systematic manner through implementation of a WSP. A WHO survey found that WSPs are globally implemented in 93 countries from every region (WHO, 2017b), however, the survey did not include information to what extent aspects of climate change have been included in WSP development. Howard et al. (2010) argue that for drinking-water supplies, management approaches are more important than technology in building resilience to climate change, and flag that many of the relevant management aspects can be addressed through a WSP.

By 2080, an increase of 5–8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (Intergovernmental Panel on Climate Change IPCC et al., 2008). Parts of East Africa are likely to experience more flooding in the future (WHO DFID 2009). Anticipated climate change for Ethiopia, where CR-WSP were piloted in two urban water supplies, includes an increase in temperature, increased frequency of droughts in some areas, while rainfall trends are hard to predict. Ethiopia has been facing an El Niño-caused drought emergency in 2015, with an estimated 5.8 million people requiring emergency water supply and sanitation (United Nations Office for the Coordination of Humanitarian Affairs OCHA, 2016). Although annual average precipitation was stable during the last 50 years, there was a decrease of 15–20% in the eastern and south-eastern semi-arid and arid areas of the country and an increased frequency of drought, while precipitation, frequency of flash floods and river floods increased in other areas of the country (Ministry of Water, 2015a). In the last 50 years, temperatures in Ethiopia have increased by 0.37 °C/decade (Ministry of Water, 2015a), and climate projections for four Ethiopian regions anticipate an increase in the average temperature by an overall 2.3 °C (3.3 °C) in the 2050s (2080s) (Gizaw et al., 2017). Long-term trends in rainfall are hard to predict as there is significant inter-annual and inter-decadal variability in the rainfall data for Ethiopia, and annual rainfall is anticipated to increase particularly in the short rainfall season in southern Ethiopia (McSweeney et al., 2006). A general increase in rainfall and temperatures with strong variabilities in rainfall during the rainy season are expected for Addis Ababa (Arsiso et al., 2018). Limited studies from Ethiopia indicate that climate change-related health problems may increase in Ethiopia, including for example a seasonal variation in diarrhoea prevalence, and a cholera epidemic following extreme floods in 2006 (Simane et al., 2017).

Addis Ababa has experienced reductions in seasonal rainfall and resulting drought, reductions in inflow into the reservoirs, falling groundwater tables and increasing temperatures leading to increased evapotranspiration from the reservoirs. Economic, industrial and population growth are expected to increase competition for water resources in the future (Worku, 2017). Taking into account water consumption, hydrological information and climate data, the unmet water demand is anticipated to increase, reaching 257–381 million m^3 by 2037 (Arsiso et al., 2017). Less overarching climate data appeared to be published for Adama, however, information on climate for the Awash Basin in which both Addis Ababa and Adama are located is available. This information indicates high variability, and projects drought intensification during April to June, flooding during July to September, and an intensification of such extreme events and a temperature increase (Taye et al., 2018).

This study provides information from a review of published case examples around the world in order to show to what extent climate-resilient WSPs have been implemented. Guidance on integrating aspects of climate change into WSP development published to date was also summarized to support future successful integration of climate change aspects within WSP implementation. A practical example that was recently completed in two urban water supplies with the involvement of the authors complements the information of this review. The example describes the experience gained from the implementation of CR-WSP in Addis Ababa and Adama, Ethiopia. The study aims at documenting the extent to which aspects of climate change have been integrated into WSP development, as well as encountered challenges and success factors in order to inform implementers and to show important supporting factors of an enabling environment.

2. Methods

2.1. Literature review on global experience with WSPs considering aspects of climate change

The online peer-reviewed database of Scopus as well as Google Scholar were searched for the terms “water safety plans” and “climate change” (more than 200 results), “wsp” and “climate change” (more than 200 results), “wsp” and “climate resilience” (84 results), " wsp” and “climate resilient” (114 results), “water safety plan” and “climate resilient” (43 results), and “water safety plan” and “climate resilience” (30 results) in April 2018. For those search term combinations with a large number of results (“water safety plans” and “climate change”, “wsp” and “climate change”), the top 200 Google Scholar results were selected in order to limit the number of documents to review. After deleting the duplicates from the searches, a total of 512 documents were included in a primary selection. In a multistep screening process, titles and abstracts of the search results were independently screened by two of the authors (B Rickert, H van den Berg) to identify the documents which met the criteria that they:

- were published in English
- were published in the period 2010–2018
- described examples of how aspects of climate change were considered/integrated into a WSP/several WSPs, OR
- gave guidance on how to consider/integrate aspects of climate change into a WSP.

The publishing timeframe starting in 2010 was applied as the manual (WHO IWA 2009) outlining step-by-step guidance on how to apply the WSP approach was published in 2009, and the first regional guidance document on how to combine the WSP approach with climate change events was published in 2011 (WHO EURO UNECE 2011).

Sources that only mentioned both climate change and WSP but did not link the two were excluded. After discussion among the authors conducting the review on any discrepancies in the screening, a total of 64 documents were selected for in-depth review. Ethiopian framework and guideline documents on CR-WSPs were included in the review, and the WHO/IWA WSP Portal (http://www.wsportal.org/?s=climate&post_type=resource) was searched. As the portal inevitably includes information that meets the requirement of providing resources that are relevant to WSP, the sources of the portal were searched for the term “climate” only. This yielded 8 more documents for in-depth review.

In total, the two authors reviewed 75 publications in-depth to assess whether those documents either described examples of how aspects of climate change were considered/integrated into a WSP/several WSPs or gave guidance on how to consider/integrate aspects of climate change into WSP. The literature review was not limited to a certain region or certain types or sizes of water supplies. Finally, details from 18 publications were included in this study. Fig. 1 shows the steps of the literature review and the number of publications included.

As only a very limited number of publications was included in the study after the selection process, the search on google scholar for the terms that resulted in more than 200 results each (“water safety plans” and “climate change”; and “wsp” and “climate change”) was repeated

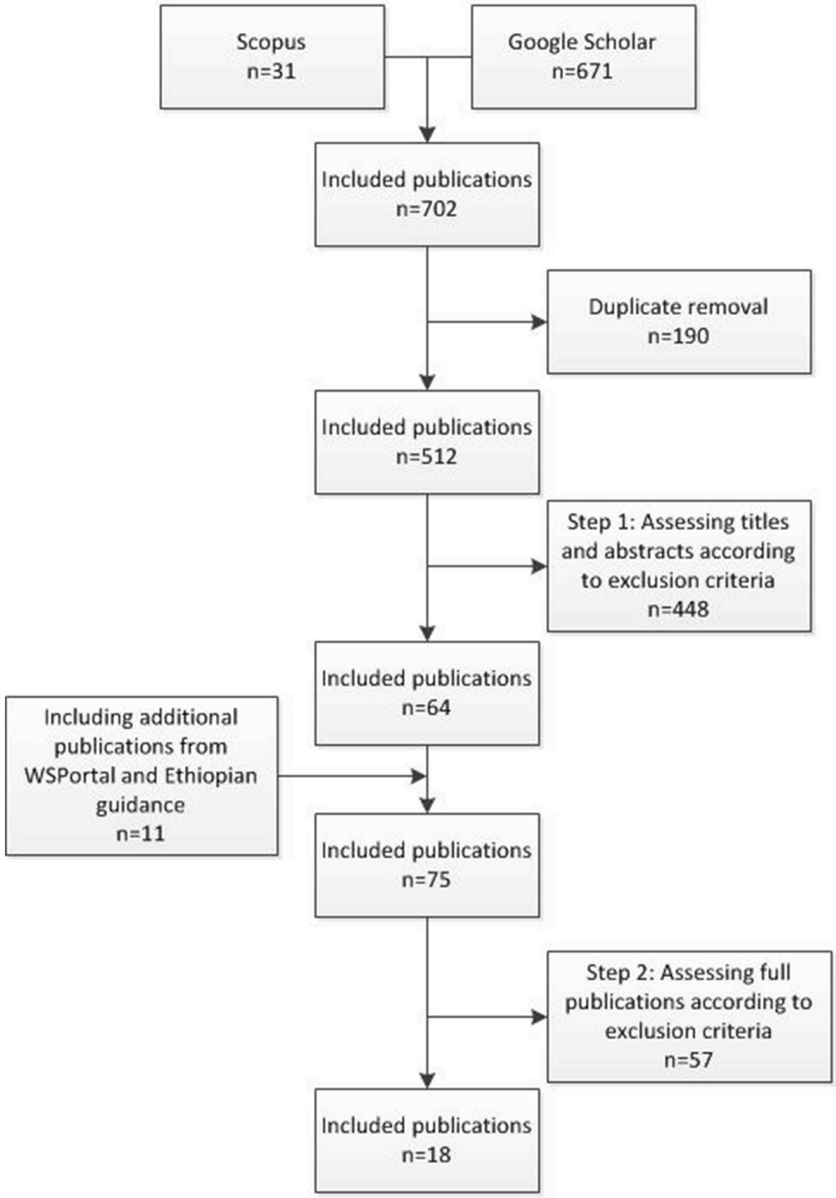

Fig. 1. Results of literature review.

in February 2019. For each combination of terms, the titles and abstracts of the first 50 results that had not been covered in the initial search were checked, and none of them was considered for in-depth review, indicating that the search results that were not checked do not include a large number of publications relevant for review for the purpose of this study. This lead to the decision to not continue scanning the titles and abstracts of all search results for these terms.

2.2. Piloting CR-WSPs in Ethiopia

Within the project Source to Tap and Back (S2TAB), CR-WSPs were implemented in the Adama Water Supply and Sewerage Enterprise (AWSSE, municipality owned) which is responsible for water and sewerage services, providing water supply service to approximately 500,000 people, and in the Addis Ababa Water and Sewerage Authority (AAWSA, government), which is responsible for providing water and sewerage services to 5 million people in the boundaries of Addis Ababa city state. Both utilities mostly use surface water as raw water sources for their supplies, and are located in the Awash basin. CR-WSPs were implemented together with actions to improve water quality monitoring in both utilities (van den Berg et al., 2019; manuscript submitted). The project results can serve both as a case example of considering climate change in WSP implementation, as well as an example of applying national guidance on CR-WSPs.

Implementation of WSPs started in 2014 in both drinking water utilities, using the Water Safety Plan Manual (WHO IWA 2009) and following the steps described therein. During the timeframe of the project, the Ethiopian strategic framework on climate resilient water safety was officially launched in December 2015 (Ministry of Water, 2015a). This strategy is accompanied by guidelines for implementation of CR-WSPs in urban water utilities (MoWIE 2015b) and in rural water supplies (MoWIE 2015c). In response to this new country-specific guidance, WSP implementation in the project was amended to integrate a focus on climate resilience, following the steps provided in the respective guidance as shown in Fig. 2.

When compared to the WHO Water Safety Plan Manual (WHO IWA 2009), the main differences include that in the Ethiopian guidance.

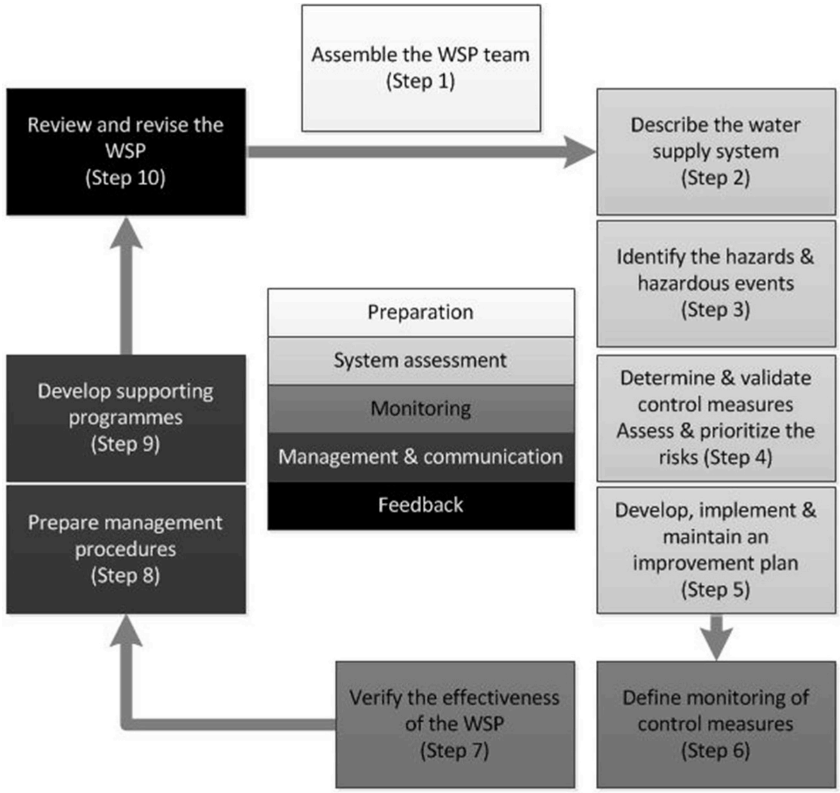

Fig. 2. Steps of CR-WSP (adapted from MoWIE 2015b).

Table 1a
Results of literature review on WSPs considering aspects of climate change: case examples.

Reference	Region	Country	Number of WSPs	Size of supplies concerned
Elala (2011)	Africa	Ethiopia	1	258,000 m^3/day
Almeida et al., (2013); Almeida et al., (2014a), (2014b); Smeets et al., (2013)	Europe	Portugal	1	650,000 m^3/day
		Netherlands	1	220,000 inhabitants
Groot et al. (2014)	Europe	Portugal	1	Ca. 3,000,000 consumers
		Hungary	2	190,000 and ca. 260,000 persons
Staben et al. (2015)	Europe	Germany	5	no info
		Netherlands	1	no info
WHO, UK Aid and MoWIE (2016),	Africa	Ethiopia	12	no info
WHO (2017a) (examples in appendix)	Western Pacific	Australia	1	Australia 10,000 residents (+500,000 visitors annually)
	South-East Asia	Nepal	5	no info
		Bangladesh	no info	no info
	Europe	Netherlands	no info	no info
	Africa	Tanzania	no info	no info
		Ethiopia	no info	no info
Shamsuzzoha et al. (2018)	South-East Asia	Bangladesh	1	4492 consumers

- the approach addresses climate aspects specifically,
- step 1 refers not only to assembling the team, but also to advocacy and communication,
- steps 3 and 4 describe a 1-stage risk assessment after validation of control measures, whereas the WHO guidance describes a 2-stage risk assessment (first without and then with consideration of effectiveness of existing control measures), and
- combines the modules of review and revision of the WSP into step 10.

As steps 1 and 2 were already completed and steps 3 and 4 were in progress when this guidance was launched, climate aspects were streamlined into the subsequent steps, but could not be considered in detail for the already completed steps.

At both utilities, teams conducted the implementation of the CR-WSP which were supported by external experts of the WHO Collaborating Centres of the German Environment Agency (UBA) and the Dutch National Institute of Public Health and the Environment (RIVM). Anticipated effects of climate change were discussed and integrated into the CR-WSP, particularly into steps 3–5. As a basis for implementation of steps 3 and 4, published and unpublished sources of lists of possible hazardous events known to the project stakeholders (including WHO IWA 2009; WHO, 2014a,b) were reviewed and merged, with a focus on the conditions prevailing in the two pilot sites, and subsequently assessed by each team in order to identify whether or not each described event was relevant to the respective water supply system.

Table 1b
Results of literature review on WSPs considering aspects of climate change: guidance documents.

Reference	Region
WHO EURO UNECE (2011)	Europe
WHO SEARO (2014)	South-East Asia
Khan et al. (2015)	Global
MoWIE (2015b)	Africa
MoWIE (2015c)	Africa
Howard et al. (2016)	Global
WHO (2017a)	Global
GWP UNICEF (2017)	Global
McKeown (2018)	Africa

3. Results

3.1. Global experience with WSPs considering climate change

The literature review showed that only limited information has been published thus far on how to integrate climate-change aspects into water safety planning with 10 sources containing case examples (Table 1a), and 9 guidance documents (Table 1b). Case examples are available from the WHO regions of Africa, Europe, South-East Asia and Western Pacific (Table 1a), and guidance documents are available from Africa, Europe, South-East Asia and for global application (Table 1b).

3.2. Approaches, challenges and success factors in integrating climate change aspects into WSP implementation

The literature review focused on drawing information from the case examples and guidance documents that described how climate change aspects were integrated in WSP implementation, as well as on success factors and challenges described for this integration following the steps shown in Fig. 2. As not all literature reviewed used the WSP terminology consistently, and did not always address complete WSPs and all aspects assessed, only limited numeric assessments could be conducted. In many case examples, CR-WSPs did not build on existing WSPs, but climate aspects were integrated within the first WSP implementation. Table 2 gives a summary of how climate change aspects can be integrated into WSP steps.

3.2.1. Assemble the WSP team

WSP teams (WSP step 1) typically include staff from all steps in the water supply system, including operators, managers and technicians (WHO IWA 2009). Additional expertise and support to consider and address the effects of climate change and to obtain and interpret climate-related information may be required (WHO, 2017a). Including expertise on meteorological data and climate change may be integrated at the outset of WSP development to enable integrating aspects of climate change into WSPs (MoWIE 2015b; 2015c; WHO, 2017a).

Including external expertise in the WSP team may already be challenging generally, and no clear information was provided in the case examples on whether experts were included as permanent members of the WSP teams or involved to a more limited extent. Some time needed to be allowed for finding a common vocabulary when stakeholders from different sectors were involved in a city in the Netherlands, such as the municipality and water board (Smeets et al., 2013).

For small-scale, low-cost and low-tech community managed systems in rural areas, it is recommended (GWP UNICEF, 2017) to involve.

- community members with knowledge on reliability, quality and seasonality of the water source,
- local or regional government officials with experience on disaster risk reduction and climate change adaptation, and
- technical advisory including hydrologists to provide information and data on climate-related variations and historical trends of water resources.

Addressing aspects of climate change in WSPs in detail may be challenging for small scale water supplies, and specific technical expertise can be difficult to access, and may need to be included at a later stage of WSP implementation (GWP UNICEF, 2017). Involving expertise on climate change is desirable, however, this may not always be realistic for all supplies, particularly small ones, which already often require independent external support for general WSP development (WHO, 2012).

3.2.2. Describe the water supply system

A detailed description of the water supply system (WSP step 2) is essential as a basis for all following WSP steps (WHO IWA 2009). To understand and address climate-related risks, information on the local climate and its changes, including for example reliability of source yields, history and trends of extreme weather events, future climate projections, potential new or alternative sources, trends in land use and population, and other water abstracters, needs to be gathered for the system description (WHO, 2017a). The influence of climate and its change on both water quantity and quality should be documented (Khan et al., 2015, WHO EURO UNECE 2011). An example of data collection is conducting regional climate vulnerability assessments that inform the system description (WHO, 2017a).

However, availability of local data, trust in the data, and how to apply the data need to be considered for this as well as for implementation of the following WSP steps. Challenges include uncertainty of predicted climate developments, and several simulations were conducted in order to be able to present a range of possible values for the availability of water resources (Groot et al., 2014). Water supply staff may have different attitudes towards the climate change topic and level of confidence in the potential results, and assigning confidence levels in order to facilitate and ensure continuous communication between stakeholders was shown to be crucial (Groot et al., 2014).

One way of dealing with limited availability of climate change data is to get started with the data that are already available (Almeida et al 2013, 2014b), integrating more data at a later stage as they become available. As there may be high uncertainty in some aspects of climate change projections, WSPs should focus on adaptation to those aspects in which there is more confidence (WHO, 2017a). Fluctuating data sets on rainfall and relatively short measuring periods may make it hard to identify statistically significant trends regarding mean rainfall (Elala, 2011) and may challenge considering climate data in assessments of the water supply.

In addition to external data collection on climate and anticipated changes, community knowledge – including experience on past events and their impacts as well as trends of climatic changes – should be the basis for integrating climate aspects into hazard analysis and risk assessment (MoWIE 2015b; 2015c; GWP UNICEF, 2017), and particularly in contexts where the community is actively involved in the water supply, they may also be involved in collecting information on past effects of climate change, which can then be combined with scientific data. Of the consumers of a water supply in Bangladesh, 67% had observed climatic risk impact on the water supply, with 29% stating that this led to the technologies frequently becoming non-functional, and the water quality deteriorating (Shamsuzzoha et al., 2018). For Ethiopia, community consultation workshops and collecting information on trends of climatic changes not only from meteorological data, but also from e.g. community elders is recommended (MoWIE 2015b).

3.2.3. Identify hazards and hazardous events, determine and validate control measures, assess and prioritize risks

The core components of WSP are identifying hazards and hazardous events followed by a risk assessment taking into account existing

Table 2
Steps of CR-WSP and summary of how anticipated effects of climate change can be addressed in each step.

WSP step	Primary climate change aspects and how to integrate these into WSPs
Advocacy, communication and assembling team (WSP step 1)	Include expertise on meteorological data and climate change Sensitization for anticipated effects of climate change and discussion on how to deal with levels of uncertainty
System description (WSP step 2)	Integrate information on climate and climate change, including areas likely affected the most, but also trends in urbanisation/population growth and respective demand changes and changes to wastewater amount and disposal, past changes in water quality in relation to changed raw water yields, trends in extreme weather events, other water users
Hazard assessment and risk assessment (WSP steps 3 and 4)	Seek agreement within the team on climate change topic and influences on hazardous events, likelihood and severity Consider changed frequencies and intensities of hazardous events, as well as new hazards, changes in exposures and new hazardous events Consider quantity implications of climate change, also taking into account competing uses and population development Make use of locally available information within the community, local authorities and water supply
Determine effectiveness of the existing control measures (WSP step 4)	Consider changes in effectiveness of control measures, and need for increased resilience of infrastructure to flooding Increase raw water monitoring in cases of extreme weather events/changes in climate to inform whether control measures are still suitable for changed conditions Validate/conduct performance testing of treatment elements under changed climate conditions and resulting changes in raw water characteristics
Improvement planning (WSP step 5)	Majority of adaptation measures need support of external stakeholders Prioritize climate-change related risks for improvement action and make existing infrastructure resilient Consider alternative/additional water sources, structural improvements for climate resilience and changes in land use
Operational Monitoring (WSP step 6)	Monitor for parameters influencing treatment steps and/or microbiological regrowth
Verification Monitoring (WSP step 7)	No detailed links found in literature review
Development of management procedures WSP step 8)	Increasingly consider emergencies due to climate change in emergency response planning and reach out to other catchment stakeholders for implementation Extend generic emergency response documentation to more specific information Plan redundancies for extreme weather events
Development of supporting programs (WSP step 9)	Build capacity on climate-change related themes Consider increased cooperation with other water users and other stakeholders, and strengthen their interventions Consider research on climate change impacts, including anticipated changes in the concentration of hazards, and changes in raw water sources resilience to climate change
Review and revise the WSP regularly and following an incident (WSP step 10)	Integrate climate change aspects as data becomes available and/or as resources for CR-WSP implementation allow Take into account new information on anticipated effects of climate change; conduct risk assessment based on scenarios and anticipated changes to risk score

control measures (WHO IWA 2009) (WSP steps 3 and 4). Climate change may particularly influence these steps by considering the introduction of potential hazards due to new hazardous events occurring, or changes in the likelihood or severity of the consequences arising from the hazard or hazardous events (WHO, 2017a). Examples include increased likelihood and magnitude of extreme weather events such as heavy rainfall and flood events introducing higher loads of hazards (WHO, 2017a). Examples for hazardous events that may become more important due to climate change include higher concentrations of enteric pathogens, microorganisms occurring at higher densities more often within the distribution system, thus increasing both severity and likelihood of occurrence and as a result increasing the risk (WHO, 2017a). Problematic source water algae and bacteria may furthermore occur at higher densities more often in source water reservoirs, caused by a number of climate change effects such as changes in temperature (WHO, 2017a).

Guidance from the WHO SEARO region suggests that a list of hazards that could be exacerbated by climate change should be drafted, and possible control measures identified (WHO, 2014a,b). For small community water supplies, it is recommended to include an assessment of current rainfall extremes, of environmental and climate-induced events (e.g. landslides, flooding, more pronounced seasonality, drought and expanding gullies), of current degradation processes in the catchment, and an elaboration of a catchment protection plan (GWP UNICEF, 2017). This guidance on small systems also gives some information on the effects of climate change on sanitation, supporting a holistic approach, and proposes to assess whether events are likely to remain the same, intensify or reduce in frequency and intensity as a result of climate change in situations where there is not enough data to assess the extent to which this is likely to happen (GWP UNICEF, 2017).

Climate change may impact water availability, water supply infrastructure and water quality, and many case examples considered aspects of climate change in hazard analysis and risk assessment. Special requirements for continuity of supply for health system components (e.g. hospitals, retirement homes) should be considered (WHO EURO UNECE 2011). With integrating climate change, WSPs shift towards a stronger focus on both drinking water quality and quantity, rather than the traditional focus on quality only. Therefore, the case examples also included trends in urbanisation, population growth and respective demand changes, and information on other water uses. One case example considered the effect of demand change on water quantity to be much more significant than the effects of climate change (Elala, 2011). In this example, meteorological, hydrological and demographical data, scenarios of anticipated changes in reservoir inflow/rainfall, estimates of future temperature and population size, and municipal water authority documents and documentation available on-site at the water supply were used, e.g. on previous issues and extreme events, in order to complement other published climate data and to assess issues that affect the water supply (Elala, 2011). In Northern Europe, higher temperatures and longer growing seasons may lead to more intensive farming and resulting water needs, increased hazard loads and shifting salt water borders due to higher water abstraction (Staben et al., 2015).

Influences of climate on hazardous events considered in the case examples generally included the following:

- changes in temperature (Elala, 2011; Almeida et al., 2013; Smeets et al., 2013; Groot et al., 2014; Staben et al., 2015; WHO, 2017a; Shamsuzzoha et al., 2018)

- rainfall extremes and droughts (Elala, 2011; Almeida et al., 2013; Smeets et al., 2013; Staben et al., 2015; WHO et al 2016; WHO, 2017a; Shamsuzzoha et al., 2018)
- changes in rainfall (Elala, 2011; Almeida et al., 2013; Smeets et al., 2013; Groot et al., 2014; WHO, 2017a)
- other developments, such as development of demand, population and distribution losses/spillage (Elala, 2011; Groot et al., 2014; Staben et al., 2015)
- sensitivity of hazards and risk factors to regional climate trends (Almeida et al., 2013)

The WSP approach was extended to a water cycle safety plan in European case examples (Almeida et al., 2014a, b, Smeets et al., 2013), addressing protection of public health, public safety and the environment. This approach not only considered the drinking-water supply, but also wastewater and stormwater systems and water bodies and their interactions. In this case, adaptation to climate change was the primary driver for the integrated approach, and hazard assessment and risk identification included assessing the potential effect of climate change trends. In the Netherlands, the WSP was complemented with a flood plan, rainfall flood risk (Almeida et al., 2013), and regional climate change preparedness, and changes in likelihood and severity of occurrence were discussed (Smeets et al., 2013). A case example from Hungary also considered economic losses or benefits due to changes in climate and land use (Groot et al., 2014).

One case example assessed potential climate and demand changes in the geographical area served by the water utility, identified climate change impacts on the company's water sources, assessed system vulnerabilities, and identified and appraised a set of potential adaptation options and measures (Groot et al., 2014). In the Netherlands, lower river flows and increased temperature were shown to lead to increased hazard concentration in rivers and increased eutrophication, and climate change potentially leading to increased salinization of rivers and bankside filtration used for drinking-water production (WHO et al 2017a). Climate change was considered when defining hazardous events, such as the impact of temperature increase, erratic heavy rainfall, increased storms, tidal surge and flooding on faecal sludge management and pollution through wastewater (Shamsuzzoha et al., 2018). Changes in climate such as temperature, rainfall and extreme droughts were considered, but also other aspects such as land overexploitation, increased per capita water demand, increased water losses in the distribution and increases in population (Elala, 2011).

In Nepal, influences of climate change on hazards and hazardous events were considered, including flood and drought events taking into account past changes in climate (WHO, 2017a). Performance testing of the treatment under changed conditions can validate the effectiveness of existing control measures in changed climate conditions (Staben et al., 2015).

3.2.4. Develop, implement and maintain an improvement plan

If the risk assessment identifies significant risks to the safety of water and shows that existing controls are not present or not effective, improvements should be identified and documented in an improvement plan to reduce the risks (WHO IWA 2009) (WSP step 5). By preparing this improvement plan, current and future risks related to climate change should be taken into account (WHO, 2017a), and possible mitigation measures for the effects of climate components and extreme weather considered (Khan et al., 2015). WHO provides a comprehensive list of examples of control measures that may become more important to manage risks posed by climate variability and change (WHO, 2017a).

In the case examples, the following improvements were described or proposed:

- Restrictions on land-use (Almeida et al., 2013)
- Increasing attention to management of demand (WHO, 2017a) and water allocation strategies prioritising water supply (Almeida et al., 2013)
- Restrictions on water use in case of droughts (Almeida et al., 2013), e.g. stipulating rules with electricity companies in years of scarcity (Groot et al., 2014), preventing the installation of irrigation pumps in the catchment area to address water scarcity during the dry season (Shamsuzzoha et al., 2018) and exploring of a transparent allocation scheme to various water users to address quantity and lack thereof (Staben et al., 2015)
- Regional water management (Staben et al., 2015), e.g. planting indigenous trees to protect the water table (WHO, 2017a; WHO et al 2016), river regulation and flow control within the drainage network (Almeida et al., 2013)
- Adapting use of a reservoir based on modelled changes in climate (Groot et al., 2014)
- Using alternative water sources, including reuse of treated wastewater (Almeida et al., 2013; WHO, 2017a), and considering increased importance of certain water sources, e.g. groundwater, in the future (WHO, 2017a)
- Installing emergency connections to neighbouring supplies (Staben et al., 2015)
- Making infrastructure flood-proof by relocation or redesigning (Staben et al., 2015; Almeida et al., 2013), e.g. making wells flood-proof (Smeets et al 2013), partly replacing a diversion channel by a pipeline to protect the intake from water of an upstream irrigation channel (Shamsuzzoha et al., 2018), ensuring protection of sluice valve chambers from flooding or water stagnation from erratic rainfall (Shamsuzzoha et al., 2018) and construction of diversion ditches and retaining walls (WHO, 2017a)
- Adding more treatment barriers (WHO, 2017a), e.g. adding ultrafiltration so that disinfection is more effective at times of high turbidity (Staben et al., 2015)
- Increase water storage capacity (Almeida et al., 2013; WHO, 2017a)
- Measures to address high velocity runoff and high depth flooding, such as infiltration systems, storage and flow control within the drainage network, terrain modelling, cleansing of surfaces, river regulation and flood resilience/attenuation measures (Almeida et al., 2013)

Many improvement measures, (e.g. reduction of pollution in aquifers), need support of external stakeholders. Doubts of staff about the reliability and importance of climate data may hamper agreement on adaptation measures (Groot et al., 2014).

In Hungary, different adaptation measures were developed for the range of future scenarios, including water supply management, water demand management, shortage consequence management, change of allocation among users, water quality management and combinations of these measures, and it was planned to build a treatment plant to be used in times of flash floods (Groot et al., 2014). Testing treatment performance under extreme conditions can help to find boundaries and inform adaptation of existing treatment (Staben et al., 2015). “No regret” measures that can reduce risks under a wide range of future scenarios of climate and development, or regardless of climate change or the extent of its effect may be prioritised for improvements (GWP UNICEF, 2017; WHO, 2017a).

3.2.5. Define monitoring of control measures and verify the effectiveness of the WSP

Monitoring is part of WSPs, and serves the purposes to validate control measures, to assess whether they are continually working as planned (operational monitoring, WSP step 6), and to verify whether the WSP as a whole works in order to provide safe drinking-water (verification monitoring, WSP step 7). The literature review showed that to date there is very little experience with integrating aspects of climate change into operational and verification monitoring. Examples described in the case examples were:

- monitoring assimilable organic carbon and biodegradable dissolved organic carbon as parameters affecting microbiological regrowth (Staben et al., 2015)
- monitoring climate and hydrological parameters (Groot et al., 2014)
- trend analysis, for example on the relation between river flow and concentration of chemicals in the raw water (WHO, 2017a).

3.2.6. Prepare management procedures

As part of WSP, clear management procedures include operating procedures when the system is under normal conditions and when the system is operating in “incident” situations (WHO, IWA 2009) (WSP step 8). For integrating climate change, climate- and weather-related emergencies may be considered (WHO, 2017a). Supporting programmes (WSP step 9) are intended to support staff's skills and knowledge, for example through quality control procedures or research and development programmes (WHO IWA, 2009). They may fill existing knowledge gaps and provide the evidence base, addressing for example capacity development on climate variability, climate change, hydrology, demand management and on flood/drought event management (WHO, 2017a). Training of operators and sensitization of communities, as well as research on changes in hazards due to climate change and in water sources' resilience to climate change can be addressed in supporting programmes (MoWIE 2015b).

In the case examples, climate change was addressed in the development of management procedures by:

- establishing a protocol with other stakeholders using the water source addressing the use in situations of scarcity (Groot et al., 2014)
- strengthening communication lines between stakeholders (Smeets et al., 2013)
- updating risk management and communication protocols (Smeets et al., 2013)
- initiating emergency responses in case of heavy rainfall events, addressing the sewage system in order to protect river water quality, and the water board initiating a communication protocol when river flooding is expected, including notification of the water company when their well field is expected to be flooded (Almeida et al., 2013).

3.2.7. Review and revise the WSP

With respect to review and revision (WSP step(s) 10) information was only found in the guidance documents. In these documents it is described that risk assessments should be revised based on future development of likelihood and severity of occurrence of hazards and hazardous events, and WSPs should be reviewed to include climate change hazards which may address quality as well as quantity aspects (WHO SEARO 2014). Regular review of new information and updating of documentation is advisable as new information on the expected effects of climate change becomes available (WHO EURO UNECE 2011).

3.3. Integrating climate change aspects into CR-WSP implementation at pilot sites in Ethiopia

Implementation of the CR-WSPs in Adama and Addis Ababa was embedded in the wider context of a project addressing several water-related aspects, which involved amongst others collection of data on source water quality and drinking water quality, improved control of wastewater discharges in the catchments, water resource protection, measures to reduce sedimentation in the catchment reservoirs, increasing access to improved sanitation, and reducing non-revenue water. The project setup thus supported the activities conducted by the utilities and helped informing the CR-WSPs with more data on water quality. Additionally, this supported them by taking measures to reduce risks in the catchment as well as in the distribution system.

3.3.1. Assemble the WSP team

The teams at both utilities consisted of staff from the water supply, as well as representatives of the Ethiopian Public Health Institute (EPHI), a governmental knowledge and research institute which amongst others conducts research on the impacts of climate change, and external experts of UBA and RIVM. The CR-WSP teams were aware of future changes such as urbanisation and water demand, however, no information on climate change was available and climate experts were not included in the CR-WSP teams as guidance documents suggesting to do so only became available within the timeframe of project implementation.

The Ethiopian guidance (MoWIE 2015b) considers under this step not only assembling the team, but also advocacy and communication. During annual workshops, both water utilities and the external experts communicated data collected within the context of the project to national stakeholders, including the WHO country office. Furthermore, such information was communicated to stakeholders involved in the other project activities, for example on resource protection, during their project meetings. Information communicated included risks identified where the utilities can only take limited action (e.g. pollution of the raw water reservoirs), and that require input by external stakeholders. This information fed into the regional and national communication processes to reach out to other relevant stakeholders, such as industries discharging their wastewater in the catchment and environmental protection agencies. On the other hand, relevant information developed under other parts of the project, including on farming and land use practices and on sedimentation in the raw water, was communicated to the teams to inform the CR-WSP. This shows that the project setup addressing for example potentially contaminating activities, as well as involving a number of stakeholders in addition to the water utilities proved beneficial to take measures which go beyond what the water utility can achieve itself.

3.3.2. Describe the water supply system

To incorporate climate change data into the WSP, both drinking water utilities addressed the following climate change information in the system description:

- aspects relevant for current and future water availability, such as industrial expansions, presence of intensively irrigated agriculture, urban expansion and population growth, and a noted increase in demand due to modernized lifestyle, hotels and urban agricultural activities,
- climate information e.g. on mean and seasonal temperature and rainfall, as well as seasonal changes in turbidity, dust occurrence and algal blooms,
- information on seasonally used raw water sources and consideration of alternative safe water supplies.

3.3.3. Identify hazards and hazardous events, determine and validate control measures, assess and prioritize risks

The teams reviewed a comprehensive template list of possible hazards and hazardous events and assessed whether the events were relevant for their supplies for the production and delivery of safe drinking water. The list included climate events already experienced by the water utilities, such as heavy rain, droughts and changes in temperature. As an outcome of the project, the template list was further complemented in order to make it applicable to a wider range of water supplies and facilitate further uptake, taking into account the experience gained within the project as well as sources published since the start of the project implementation (Rickert and van den Berg, 2018). For all relevant hazardous events, the teams assessed the risks based on the definitions of likelihood of occurrence and severity of consequences and matrix included in the national guidance (MoWIE 2015b).

One of the most relevant aspects of including climate change aspects into the development of WSPs is to consider the occurrence of new

Table 3
Examples of hazardous events related to climate conditions considered by the teams in implementation of CR-WSPs in Addis Ababa and Adama.

Event
Heavy rainfall leading to increased overland flow and introducing physical and chemical hazards to the source water
Reduced vegetation covering the catchment area and deforestation leading to dusty surfaces, and potentially shortage of water, and increased erosion of the area
Widespread water succulent weed uses a lot of water and thus has effect on source water quantity
Landslides accelerate erosion, leading to increased introduction of hazards to surface water body
Climatic variations lead to increased/reduced water flow or flooding, influencing hazard transport and/or quantity available
Extended drought periods lead to accumulation of deposition on surfaces, and to enhanced run-off due to reduced absorption capacity
Topsoil is washed into surface water body after dry season
Changed catchment conditions (e.g. climatic changes, increased surface sealing, landscaping activities) create new/changed hazardous events
Reduced flow/water stagnation in winter season causes algal blooms
Seasonal changes of water quality may cause taste and odour problems and will affect drinking-water treatment processes (e.g. algae, iron, turbidity)
Sudden increases in the rate in which water passes through the filter will shake loose particles that have already been trapped in the sand, causing “spikes” in the turbidity, and may reduce removal of particles
Water temperature is too low to allow for efficient chlorination so that pathogens are insufficiently removed
Chlorination is not adapted to fluctuations in raw water quality and flow variations, leading to insufficient reduction of pathogens
Lack of preparedness for recurring disasters causes interruption to the process or poor water quality
Storage containers/jars kept at ground level allow for contamination to enter from water pooling during rainy season

hazards and hazardous events that may introduce contamination of the drinking-water supply, as well as anticipating changes to the frequency of occurrence of hazards and hazardous events, their intensity, and possible responses to their occurrence. A number of hazardous events which were anticipated to be related to climate conditions were considered by the CR-WSP teams in Addis Ababa and Adama (see Table 3), preparing the utilities for future impacts of climate change. Teams discussed possible future changes of the events and their relevance for their water utilities.

Risks for hazardous events relevant to the respective supplies were assessed regarding their current likelihood of occurrence and severity of impacts with a particular focus on the events in the catchment in Adama and the distribution system in Addis Ababa respectively.

3.3.4. Develop, implement and maintain an improvement plan

Using the comprehensive table documenting all risks relevant to the two utilities, the teams drafted improvement plans for high risks from which they selected some as “quick wins” which could lead to visible progress within the project timeframe and for which funding was provided under the project. Improvements with a link to climate change included planting trees in order to reduce dust affecting the treatment during the dry season, planting another 12,000 trees in the catchment to reduce the amount of run off and erosion, and building sediment traps to reduce hazards entering the source water by run off during rainfall. If competition for the available water resources should intensify as a result of climate change, reducing non-revenue water can have a positive effect on the amount of drinking-water available, addressing quantity issues not only at the raw water source, but also through measures at later supply steps. Activities to reduce non-revenue-water were conducted under another part of the project.

3.3.5. Define monitoring of control measures and verify the effectiveness of the WSP

Drinking-water quality testing and operational monitoring have been expanded and the laboratories at the water utilities have been capacitated and further equipped to facilitate improved monitoring. Adapting monitoring in relation to the improvement measures implemented as quick wins may be considered in future review and revision of the CR-WSP process.

3.3.6. Prepare management procedures

At both utilities, emergency plans were drafted during project implementation. New aspects related to climate change were integrated, such as considering flash floods more prominently in the emergency response plans.

3.3.7. Develop supporting programmes

Several activities which can be subsumed under supporting programmes were already in place at both utilities, such as creating awareness for consumers and population in the catchment (farmers and industries). Ongoing research and research considered for the future with relevance to the influence of climate change on water safety covers aspects of non-revenue water and water losses, looking into options to improve wastewater removal, raw water quantity and quality including pathogens and the occurrence of algal blooms, as well as the influence of heavy rainfall and algal blooms on the performance of the treatment plant during extreme weather events.

3.3.8. Review and revise the WSP

During the project implementation phase, integrating climate aspects focused on the above mentioned points and on later WSP steps, and did not yet take into account projections of changes due to climate change in the future and integration into earlier WSP steps, which may be considered in a later review and revision of the CR-WSP process.

4. Discussion

Implementation of CR-WSP as a proactive approach provides a good basis for being prepared for anticipated effects of climate change, including increased frequency and extent of related hazardous events in the water supply such as flooding and droughts. A reactive approach to adaptation after water shortage or damage will likely lead to higher costs, longer downtimes for water supply and negative image effects, while a risk-based approach enables to integrate adaptation measures (Staben et al., 2015), making a case for adapting to the anticipated effects of climate change through their integration into WSP implementation.

The literature review showed that there is only limited information published in English on how to integrate climate-change aspects into WSPs. Case example information was published from locations in the WHO regions Africa, Europe, South-East Asia and the Western Pacific, but not from the Americas or the Eastern Mediterranean region. Several guidance documents are available for Africa, Europe, South-East Asia and for global application but not for the Americas, the Western Pacific or the Eastern Mediterranean regions. This may in part be due to the literature review being limited to documents published in English. In order to facilitate implementation of CR-WSPs at national levels, respective national guidance may either be developed if not yet in place, or existing WSP guidance may be revised or complemented with advice on climate integration, depending on the setting. The case examples that provided information on the size of the supplies showed a clear bias towards large urban utilities, with only one of the supplies serving < 5000 persons, however, generic guidance documents are available for both small (e.g. MoWIE 2015c; GWP UNICEF, 2017) and large (e.g. MoWIE 2015b) supplies, or without focus on a certain supply size.

Integrating aspects of climate change into WSPs is particularly important for small supplies due to their vulnerability to climate change, however, it may also be particularly challenging for them. Small-scale drinking water supplies that rely on a single source are expected to be particularly affected by climate change (Bloetscher et al., 2014). In Ethiopia, rural water schemes are often located near river banks, or located in places prone to runoff and flooding (MoWIE 2015c), making consideration of potential changes to such events particularly important for such supplies due to their vulnerability. Furthermore, integrating aspects of climate change strengthens the focus on water quantity available, and as a result, source selection and considering additional water sources (Worku, 2017) are relevant. Particularly approaches taken for small supplies often do not only regard the effects of climate change on water safety, but also on potentially polluting activities such as sanitation (Shamsuzzoha et al., 2018, GWP UNICEF, 2017).

Aspects of climate change were particularly addressed in the steps of system description, hazard analysis and risk assessment, improvement planning and development of management procedures. While consideration of climate change aspects in other WSP steps, such as operational and verification monitoring, may follow from the outcomes of consideration in the other WSP steps (WHO, 2017a), documentation of case examples showing what this explicitly looks like in practice would be helpful to support future uptake. The main differences in comparison to “classic” WSPs identified in the literature review and the pilot project in Ethiopia are that addressing aspects of climate change typically leads to.

- increased reaching out to other stakeholders in order to obtain and interpret data on climate change, as well as for adaptation measures and involvement in case of climate-induced emergencies,
- increased discussion on the reliability of data underlying the WSP, particularly the risk assessment,
- a stronger focus on quantity, in addition to water quality, resulting in a need to also consider other aspects, such as developments in population, industry and water demand,
- some overlap between the steps of identifying hazards and hazardous events and assessing the risks, and the step of preparing management procedures, as events such as e.g. droughts and floods may be considered as hazardous events and as emergencies, and thus be addressed in both steps,
- complementing the risk assessment for a certain point in time with projections of expected changes to the risk assessment in the future, and
- in some cases changes to the risk score when based on scenarios and anticipated changes.

Relating to the third bullet, also in the CR-WSP implementation in Addis Ababa and Adama, water availability, consideration of extreme weather events in the hazard analysis and risk assessment, as well as in the emergency response procedures, and reaching out to external stakeholders were considered as relevant aspects.

Availability of climate data, especially in a form that can be easily used by utilities, as well as staff perception of reliability of the data may be an issue, and future CR-WSP development should pay particular attention to communication in this context. CR-WSPs may start with available data (Almeida et al., 2014b), for example on past climate-related events and changes, and identify data needs for future integration during review and revision, taking an approach of integrating aspects of climate change incrementally at an appropriate and manageable level of the amount and complexity of data used. This would also be a feasible approach when integrating or strengthening the consideration of climate aspects in an already existing WSP, rather than considering this in implementation of a new WSP from the start. As one outcome of the project in Adama and Addis Ababa, the CR-WSP implementation informed research to have a focus on climate aspects influencing raw water quality, and the influence on the performance of the treatment plant during extreme weather events. Results will then be able to inform future review and revision of the CR-WSPs, allowing for incrementally integrating information as it becomes available. Furthermore, the project setup including options for exchange with a large number of stakeholders involved in other project areas and generating valuable data that could be used for the CR-WSP implementation proved to be beneficial. While regional or global guidance needs to remain generic, implementation at the local level requires climate data for the locality of the water supply, and possibly also guidance on how to integrate this information.

Many publications included current climate aspects into the WSPs, and to a lesser degree addressed actual anticipated changes in the mid- and long term and the related effects. In order to define a useful and sustainable adaption strategy, knowledge about the expected changes in climate has to be built up, and based on this, the vulnerability of the region and the system can be examined (Staben et al., 2015). Some tools are developed to provide more knowledge/awareness on the effect of climate change and its impacts. One tool providing information on floods and droughts, including for water utilities, is the Flood and Drought portal (http://www.flooddroughtmonitor.com), and a methodology is being developed on how this information can be linked to WSPs (Damons, 2018). The U.S. Environmental Protection Agency (EPA) prepared a Climate Resilience Evaluation and Awareness Tool (CREAT) to assist drinking water, wastewater and stormwater utility owners and operators in understanding and addressing climate change risks (U.S. EPA, 2016). Although not strictly linked to WSP, this information can nevertheless inform risk assessments and response plans. Information on further tools, data sources and guidance documents is also given in the guidance on climate-resilient WSP (WHO, 2017a). Understanding how climate change will alter risks may need to be increased as a basis for becoming more resilient against increased rainfall and flooding (Worku, 2017).

While some information on climate, e.g. experiences on past climate-related events, will also already be available at the local level, providing information at the national level is an important success factor, particularly when WSP development should consider future anticipated changes of the climate. Action that can be taken at the national level to support uptake of CR-WSP includes collaboration with experts in climate change, hydrology, and meteorology to understand the likely extreme weather events (nationally and locally), conducting pilots incorporating climate risks in WSPs to increase resilience, developing guidance documents, considering changes in policy and regulation for water supplies to cope with climate change risks, and preparing case studies (WHO SEARO 2014). In Ethiopia, it was recommended to provide advocacy and awareness raising activities for, amongst others, water and health sector staff to improve understanding of the risks posed by climate variability and change, and the National Meteorology Agency (NMA) was to develop drinking water sources vulnerability and adaptation assessments at the climatic zone level to be used by the water suppliers (MoWIE 2015b).

Events such as flooding and droughts have been addressed in the case examples, guidance documents and Ethiopian pilot project both in hazard analysis, as well as in management procedures, particularly emergency response planning, somewhat blurring the lines between the traditional distinction between normal operating conditions and emergencies, and between WSP steps. Thus, in addition to the generic emergency response plan which is traditionally an element of WSP development (WHO IWA 2009), more specific emergency responses may need to be developed for types of emergencies such as floods and droughts. For Ethiopia, recommended response actions depending on the type of emergency situation include modification of treatment of existing sources, temporary use of alternative sources, water tracking during water scarcity, responses in case of gross contamination and in case of damage to the system due to flooding, and increase of disinfection points (MoWIE 2015b). Past trends of drought and flood assessment are considered important for emergency preparedness and to develop emergency response plans and standard operating procedures on how to operate the system during the respective situations (MoWIE 2015c), and the pilot sites in Adama and Addis Ababa integrated aspects related to climate change in their emergency response plans. Such an approach would also be beneficial at other locations in other regions experiencing similar climate change impacts.

As a stronger focus on climate aspects in WSP implementation initiates increased attention on water availability and quantity, this requires attention to other areas, such as population and water demand, and the anticipated future development of these factors. Responses to reduced water quantity available may not only cover the development of other water sources, but can also include improving water demand management in a water supply (WHO, 2017a; Worku, 2017), adapting water tariffs, improving domestic water use technology efficiency and water harvesting (Arsiso et al., 2017), and reducing non-revenue water as implemented at the pilot site in Addis Ababa. These are areas that water suppliers typically have more influence on than on competing demands in the catchment that involve multiple stakeholders.

The Ethiopian setup of expressed policy commitment and national guidance for practical implementation trialled in the pilot projects in Adama and Addis Ababa provided a solid basis for the implementation of CR-WSPs. The Ethiopian guidelines for implementation of CR-WSPs in urban water utilities (MoWIE 2015b) provided a good basis for guidance on the process of WSP implementation, however, challenges in application included that they only became available after the project had already started, and that they included limited detailed information on how to integrate local data on climate and climate change in the WSP process, thus making incremental integration of these aspects into WSPs feasible. Generally, a lot of literature exists on how climate change is anticipated to influence drinking-water supplies, however, much less literature on how this information can be applied within the context of developing or revising WSPs as provided in this study.

The list of hazardous events, including those caused or influenced by climate change, developed under the project fills this gap for the step of hazard assessment, providing practical guidance on which climate-related hazardous events to consider in future CR-WSP implementation, particularly in Ethiopia. However, as experience with the application of CR-WSP increases, evolving information also needs to be included in such tools to make application more relevant for other settings and other types of supplies, including small ones, as well as integrating information on other WSP steps, such as possible control measures and requirements for adapting operational and verification monitoring.

5. Conclusions

Literature reviewed shows that aspects of climate change have been integrated in WSPs in diverse regions of the world and in large as well as to a lesser extent in small water supplies, making water suppliers more resilient to the anticipated effects of climate change than a reactive approach would. Publications include information on how this integration was conducted, and different challenges and success factors which can support water suppliers who wish to implement CR-WSPs. Future scale-up of this combined approach is supported as more guidance documents become available. International or regional guidance should be complemented with national guidance and tools with practical information on the anticipated effects of climate change at the local level, and how these can be used for WSP development. Depending on the local setting and the particularities of the single water supplies, generic guidance will need to be adapted for practical application. Practical guidance such as the list of hazardous events developed under the pilot project in Ethiopia supports this, and can be adapted and updated as needed and as more information becomes available. Particularly for small supplies, availability of practical easy-to-use guidance is important in order to facilitate uptake of including current climate information and projected changes into WSPs.

This study focused on considering climate change in WSP development, however, only limited information was included in the literature reviewed on climate change impacts on polluting catchment uses and practices such as sanitation and agriculture. In order to facilitate taking a holistic approach that considers not only water supply but also other water uses and wastewater management, information from piloting such broader approaches, as well as guidance is needed on how to consider the effects of climate change for these aspects in WSP development.

Conflicts of interest

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