MUISKA: multidimensional approach for risk assessment of an intermittent water system

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1 ABSTRACT

Despite its vast reach, the term water security remains challenging to ground into actionable daily water risk scenarios. From its introduction 20 years ago by the ministerial Declaration of The Hague on Water, to its adoption by development actors, water professionals, academia, and governments–various theories, methodologies, and approaches have been published. Failures to advance SDG6 signal a clear need for an approach that includes multiple water-security risks at basin level to improve water and land planning. Here we present MUISKA, **MU**ltidimensional r**ISK A**ssessment, an approach to assess and compare multiple water-security risks at basin level. In this paper, we explore the development of the first three steps of this approach by the identification of water service perceptions using surveys in Cajibío, a municipality highly affected by the armed conflict in Colombia. The MUISKA approach allowed us the identification of intermittent water supply as an important and complex water security issue in Cajibío. Based on multiple-actor participation, systems perspective, and notions of hydrocomplexity, MUISKA facilitated the documentation and assessment of complex and competing water-security scenarios.

2 INTRODUCTION

Since the year 2000, development institutions and researchers are advocating for achieving water security to guarantee the right amount and quality of water for its different uses and for ecosystem conservation, in a climate of peace and justice in territories (Global Water Partnership, 2000; Ministers and Heads of Delegation, 2000).

Despite of multiple efforts to achieve the goals of the SDG6, the current progress on six out of 11 indicators demonstrates that global society is not on track yet of achieving water security and we are losing some water-related ecosystems, or their water quality is deteriorating (UN, 2021; WHO et al., 2021). Because of global consolidation of climate change, water insecurity is manifesting as less water availability (droughts and poor water quality), reduced animal and livestock health and productivity, reduced fisheries yields and aquaculture production, increased incidence of infectious diseases (e.g., water-borne and vector-borne diseases), migration and displacements because of climate extremes, inland flooding, and flood or storm induced damages in coastal areas

(H. O. Pörtner et al., 2022). With high confidence, the IPCC (H. O. Pörtner et al., 2022) stated that economic and societal consequences of water insecurity are more pronounced in low-income countries than in the middle- and high-income ones, which is a long-lasting situation for millions of people in the world.

Water insecurity materialises in intermittent water supply systems (IWS). Under IWS, users receive less than 24/7 water service, see Figure 1. One key characteristic of IWS is the downward spiral effect on the supply system, which culminates with the loss of trust of people in the water utility. This may create additional problems outside of supplied area such as increased consumption of bottled water, which is produced by additional treatment of water from other water sources, either surface or groundwater, at the same or different river basins.

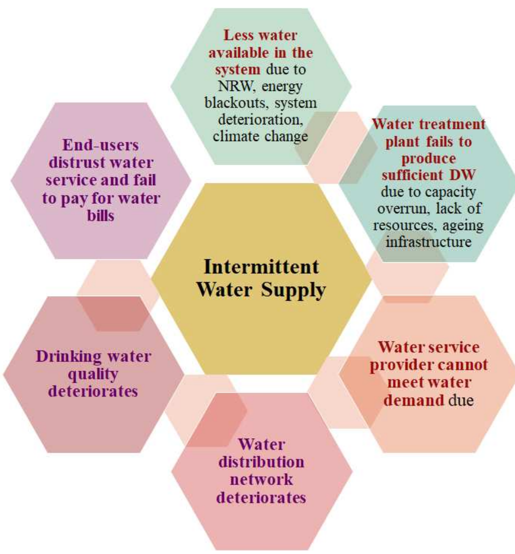


Figure 1. Negative effects of Intermittent Water Supply (IWS)

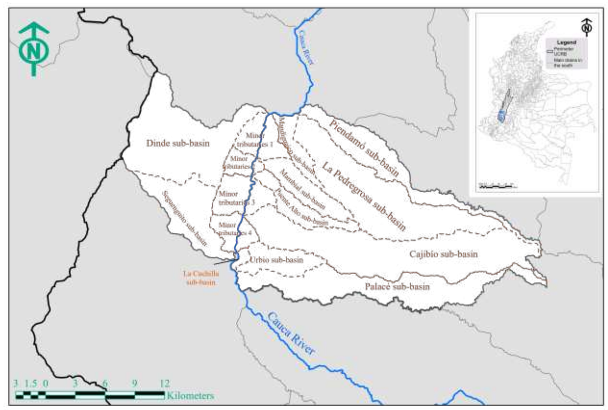


Figure 2. The Cajibío Municipality at the Upper Cauca River Basin

In Colombia, coverage of safely managed drinking water and sanitation services in is lagging. Salazar (2019) studied the overall alignment of the country to SDG 6 indicators and found that one of the most staggering difficulties is the gap between rural and urban areas, as well as the lack of a unified source of data reporting. Although the overall national coverage levels are relatively high when compared to other countries in the region, Colombia faces important challenges in terms of the quality and continuity of drinking water and sanitation services. The situation in rural areas is of concern, FINDETER (2021) recently reported that 76% of water treatment facilities are not operating in rural areas or do so intermittently, because of inadequate operation and maintenance systems, and of these, 39% need to be completely rebuilt.

IWS is a common mode of water supply in Colombian cities, and its impact on water security at the population level has not been studied, especially in municipalities affected by the armed conflict, which are prioritized within the *Development Programs with a Territorial Approach* (PDET municipality in Spanish,). Therefore, we aim to analyse the risk of contamination of stored water at households caused by IWS in the municipality Cajibío – Colombia, by the application of MUISKA (**MU**ltidimensional r**ISK A**ssessment). In this paper, we explore the development of the first three steps of this approach by the identification of water service perceptions using surveys. MUISKA is an approach to assessing and comparing multiple water-security risks at basin level. MUISKA incorporates the principles of hydrocomplexity (Kumar, 2015), systems perspective (Meadows, 2008), and adopts the definition of disaster risk (IPCC, 2012) to identify water-security risks in terms of hazards, exposed populations or assets, and vulnerabilities. This approach also incorporates the explanation of uncertainties and judgements of the strength of the knowledge to produce valid risk assessments (Aven, 2020).

3 METHODOLOGY

3.1 The water supply system in Cajibío - Colombia

Cajibío is a Colombian municipality at the Upper Cauca River Basin (see Figure 2), in the Department of Cauca, at 1,765 m.a.s.l. Water sources cross its territory, such as Cajibío, Palacé, Piendamó, Urbio, Pedregosa, and Cauca Rivers. The urban centre, 13 smaller villages, and 45 townships compose this municipality. It holds a population of 32.237 inhabitants, of which 4.5% live in the urban areas and 95.5% in rural areas. Cajibio's economy depends mostly on agriculture (coffee, sugar cane, plantain, beans, corn, and cassava). Small bovine and chicken farms also contribute to the town's productivity, as well as forestry plantations for timber harvesting (Instituto Cinara & Universidad del Valle, 2017). Cajibío is a PDET municipality, with a high level of poverty, inequality, presence of illicit economies and institutional weakness, which make urban-rural dynamics complex.

The water utility APC Cajibío supplies water, sanitation, and solid waste management services to some urban and rural areas. The cooperative serves 2,989 households, of which 839 are in the urban area and 2,150 in the rural area. APC Cajibío holds a collective supply system, the water inlet locates at Michicao stream, at the Jebalá indigenous reserve in the Totoró municipality. The water treatment plant uses conventional processes, including final disinfection with chlorine, and the water distribution network is branched and operates by gravity (Instituto Cinara & Universidad del Valle, 2017).

3.2 Formulation of MUISKA

We selected a pool of 36 key publications about water security and risk science for full reading and construction of the conceptual framework that supports the design of MUISKA. Here, we present the key concepts.

3.3 Surveys

The survey campaign occurred between August 22 and September 30, 2018, in the Cajibío municipality. The survey covered 11 urban and 19 rural neighbourhoods of Cajibío, representative of the 2447 water users in 2018. Researchers surveyed 260 household water users using a questionnaire to identify the overall user perceptions of their water service (Martínez et al., 2018). The survey campaign ran under the authorisation of the Ethics Committee of Universidad del Cauca; researchers got informed consent after explaining the scope of the project and all questionnaires were anonymised. Researchers administered the questionnaire to individual randomly selected households.

We analysed the survey results using SPSS 27. The process encompassed three steps. First, we assessed the overall profile of the survey with the description of age, strata, and educational level of the respondents. Second, overall service perception and its relation to service continuity were assessed using Likert-scale questions. Third, based on service continuity questions, we identified predominant household water management strategies (See Table 1). We then integrated these results into the overall risk assessment of stored water contamination from IWS in Cajibío using MUISKA.

Table 1. Three categories of questions included in the questionnaires

Service perception	The water supplied by the company has a good colour, smell and taste. When damage is reported to the water company, it is resolved satisfactorily and promptly. There is never any damage to pipes, connections and meters in your neighbourhood. The water company inspires trust in the provision of water services.
Service continuity	The water service in your home is not permanent. Approximately how many hours do you receive drinking water service in your household? Applies for the "Winter" and "Summer" seasons.
Household water practices	At home, I collect rainwater for food preparation. I store water in clean and covered containers. For cooking, I use the water that is supplied by the water company. I boil the water consumed in the house (beverages). I use filters to purify the water.

3.4 Risk analysis for the water contamination because of IWS at the Cajibío municipality

In this paper, we present a preliminary risk analysis of the contamination of stored water as one consequence of IWS in Cajibío - Colombia, which allows to test the phase of identification and prioritization of impacts to be analysed under the integrated perspective of MUISKA. Following previous work done in this municipality (Martínez et al., 2018) and fieldwork conducted in October 2022, we describe the application of MUISKA for the steps 1 to 3 and describe qualitatively the factors we should consider for the future development of the steps 4 to 6, based on the learning of the Cajibío analysis for extending to a specific water security hazard existing in a municipality at the Upper Cauca River Basin.

4 RESULTS AND DISCUSSION

4.1 Conceptual framework for MUISKA

4.1.1 The concept of risk

In this work we consider an operational definition of risk: risk should be logically sound, reflective of scientific expertise, reflective of public values, responsive to social concerns, and acceptable to experts, the public, and decision makers (van Asselt, 2000). In the rest of this paper, we will refer to the risk of contamination of stored water caused by IWS in the urban area of Cajibío.

4.1.2 Systems thinking and hydrocomplexity

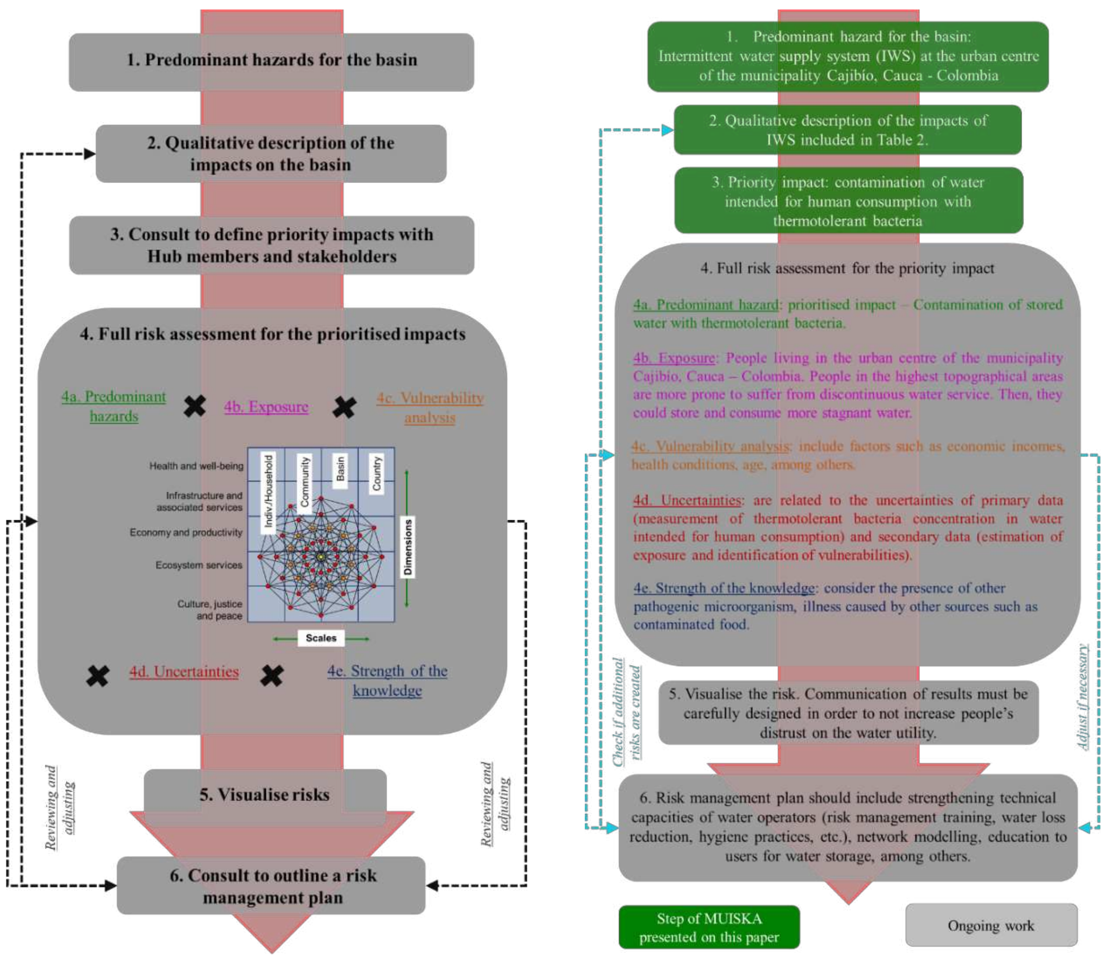
Water-security risks should be approached from the system thinking theory (Meadows, 2008) since a water system can be conceived as a system with natural and artificial structures; functions such as support, provision, regulation, and culture; and interactions among its components (Haileslassie et al., 2020). Moreover, water systems are dynamic across time and space and are governed by formal and informal institutions (Haileslassie et al., 2020). Water-security risks are complex and operate and impact on a range of scales and dimensions. Adding to the complexity, populations and physical assets may have multiple vulnerabilities. To explain the complexity of human and societal interactions with water systems, where a web on intricate dependencies across biotic and abiotic subsystems exists, Kumar (2015) introduced the concept of hydrocomplexity. Hydrocomplexity is "*an integrated approach, aimed at taking a broad contextual view of water in all its complexity to seek principles and methodologies to unravel the interactions across hydrosphere, biosphere, atmosphere, cryosphere, lithosphere, and anthroposphere*" (Kumar, 2015).

The complexity of IWS is reflected in the several causes causing intermittency, such as water scarcity, excessive water losses or energy blackouts. When this happens, there is less water available in the network, generating irregularity in the water service. This mode of water service has additional negative effects, such as pipe deterioration and leakages (Agathokleous & Christodoulou, 2016). In addition, irregularity in the water service favours the establishment of water storage behaviours. Thus, intermittency leads to ingress of pollution into the network and creates conditions for growth, transmission, and persistence of water-borne pathogens (Bivins et al., 2017). The resultant decline in water quality in the system increases risks to consumers' health. It can also cause a decrease in water consumption and ultimately disengagement of users from the water supply system (Kaminsky & Kumpel, 2018). This establishes and reinforces a spiral of decline in the overall water service; the lack of continuous (or 24/7) water availability discourages end-users from paying for water services ultimately impacting on the financial viability of the water utility, which can no longer operate and maintain the water supply infrastructure, further exacerbating the conditions for poor service delivery (Galaitsi et al., 2016).

Therefore, IWS is a systemic risk because of multiple negative and positive feedback loops. In IWS, various uncertainties exist because of the cascading impacts within the scale in which the risk is located and, in this case, beyond the municipal scale (Renn et al., 2020).

4.1.3 MUISKA structure

Our general approach has six steps, as shown in Figure 3a. MUISKA includes four general scales of risk: individual/ household community, river basin, and country and five dimensions where impacts can occur: health and wellbeing, infrastructure and associated services, economy and productivity, ecosystem services, and culture, justice and peace (see Figure 3a).



a) General structure of MUISKA b) Analysis of IWS in terms of MUISKA

Figure 3. General structure of MUISKA and its application to IWS

Involving stakeholders in risks assessments, including decision makers, brings a sense of reality and purpose (Hope, 2006), can help build trust, where risk management is based on, and could promote the incorporation of risk assessments for land and water planning. Therefore, this approach can be understood as a participatory process and first-order assessment of water-security risks in river basins. A stakeholder analysis for the water utility APC Cajibío made in 2018 showed that the closest organisations are the mayor's office and the Planning Department, followed by the company EMCASERVICIOS (manager of the Departmental Water Plan for the Department of Cauca). The relevance of the relationships with these institutions is high. The relationship between APC Cajibío and the regional environmental agency CRC (Corporación Autónoma Regional del Cauca) is also a highly relevant but a distant one. APC Cajibío also keeps close relationships with the Community Action Boards from the urban and rural areas, but their relevance is medium (Martínez et al., 2018).

4.2 Survey results

The overall profile of the survey respondents is presented in Table 2. Most showed being of *Low-Low (73.3%) and Low (24.8%)* socioeconomic strata, while the majority showed having attended until primary (36.5%), secondary (18.5%), and high (17.7%) school level of education.

Table 2. Socio-demographic characteristics of survey respondents

Variable	Values	N	%	Variable	Values	N	%
Socio-economic Strata	Low-Low	189	73.3%	Education Level	High School (up to 11)	46	17.7%
	Low	64	24.8%		Postgraduate	4	1.5%
	Medium-Low	4	1.6%		Primary School (up to 5 °)	95	36.5%
	Medium	1	0.4%		Professional	12	4.6%
	Medium-High	0	0.0%		Secondary School (up to 9 °)	48	18.5%
	High	0	0.0%		Technical	38	14.6%
					Technologist	17	6.5%

When asked whether water service to their households is permanent (or not), survey respondents expressed differential experiences. Table 3 shows 31.9% agreed and 33.5% disagreed with the statement "the water service in your home is not permanent". This provides an outlook on the differential experience of service continuity in household water service.

Table 3. Perception of water service continuity delivered by APC Cajibío, Cauca

Variable	Value	N	%
The water service in your home is not permanent	Strongly agrees	22	8.5%
	Agrees	83	31.9%
	Neutral	50	19.2%
	Disagrees	87	33.5%
	Strongly disagrees	18	6.9%

The hours of service reported by survey respondents can be found in Table 4. Notably, there are no clear tendencies of in the report of respondents on the different categories of serviced hours. This result goes in line with the one observed in Table 3 to signal a differential experience of intermittency among survey respondents.

Table 4. Hours of household water service delivered by APC Cajibío, Cauca

Variable	Value	N	%
Hours of household water service during "Summer" season	No knowledge	54	20.8%
	Less than 10 h/d	45	17.3%
	Between 10 and 18h/d	52	20.0%
	Between 18 and 23h/d	57	21.9%
	Between 23 and 24h/d	52	20.0%
Hours of household water service during "Winter" season	No knowledge	62	23.8%
	Less than 10 h/d	56	21.5%
	Between 10 and 18h/d	46	17.7%
	Between 18 and 23h/d	53	20.4%
	Between 23 and 24h/d	43	16.5%

4.3 MUISKA application to IWS in the municipality of Cajibío

4.3.1 Step 1: IWS as a water security hazard in Cajibío

The water treatment plant used by APC Cajibío was designed to treat 17 L/s but currently treat 25/s. This results from an unplanned transformation of rural areas into land plots to build houses[1]. The distribution network has not been expanded to supply this quantity of water continuously and under adequate pressure conditions. Therefore, the water operator must supply water for a few hours per day to rural areas and the supply is almost continuous in the urban zone to guarantee drinking water to schools and hospital. However, the neighbourhoods at the upper zones in the urban area receive fewer hours of water supply per day (supply stops in the evenings) because the water flows to lower areas. This situation drives users to store water at home in tanks for cleaning and hygiene purposes and in buckets to cook and drink. Survey results show 38.8% and 24.2% of water users choose to "always" or "often" store water in clean, covered containers.

The poor performance of the treatment processes, together with pipe leaks and their respective repair activities, might deteriorate the water quality. Thus, users also prefer to boil water, buy bottled water, or employ filtering devices to improve water quality at home (Survey results show 59.6%, 11.5% and 17.7% of water users choose to "always", "often" or "sometimes" boil water for their consumption at home). In this line, end-users might be more exposed to water of deteriorated quality, survey results show 69.2% and 21.2% of water users choose to "always" or "often" use the water supplied by the water company for cooking, and most respondents showed never (65.4%) or rarely (12.7%) use a water filter. Extended time of water storage and boiling

[1] Informal conversation with one staff member of the water utility APC Cajibío – on 4th October 2022.

water cause loss of free residual chlorine. This, together with poor hygiene practices in households (e.g., access of animals to water used for human consumption, poor hand washing before cooking food or after using the toilet), can lead to further water contamination.

4.3.2 Step 2: Qualitative description of IWS's consequences by scales and dimensions of MUISKA

Table 5 qualitatively describes the consequences of IWS per each scale and dimension proposed by MUISKA. Most of the impacts occurred at individual/household scale and in the dimension infrastructure and associated services, followed by health and wellbeing and economy and productivity. The dimension ecosystem services at individual/household scale could be benefited by the reduced water demand from the source supplying the water system. At the community level, some consequences can be present in each dimension. Few impacts occur at the river basin and none of them are felt at the country scale.

4.3.3 Steps 3 through 6: water contamination as prioritised impact of IWS

According to our description of IWS as a water-security hazard (Step 1), one prioritised impact is the contamination of stored water in households. One co-author is currently surveying IWS and water quality in Cajibío. This research will allow a deeper understanding of IWS and its relationship with service perception and water quality.

Step 4 is about the full risk assessment of the contamination of stored water with thermotolerant bacteria, which is intended for human consumption (see Figure 3b). Thus, this risk assessment will be focused on the dimension of health and wellbeing by identifying who is drinking contaminated water and how much water those people are drinking (exposure). Similarly, the risk assessment could also be done for the dimension culture, justice, and peace by evaluating the risk related to the distrust from end-users towards the water utility. It is also necessary to identify the conditions of those exposed people regarding the base health conditions (previous exposure by the same and other routes –e.g., food-, vaccination, other health risk factors, current chronic diseases, etc.), age, gender, socioeconomic incomes, among others (vulnerability). The full risk assessment should also describe the uncertainties associated with the method used to measure the concentration of thermotolerant bacteria and with the estimation of exposure and vulnerability. Finally, the strength of the knowledge judgement includes the acknowledgment of the existence of other exposure routes to thermotolerant bacteria and other pathogens.

The Step 5 covers the risk communication. For this, it is important to be sensitive about the way we communicate the results to avoid naming responsible people or institutions. Instead, we should tailor the message to promote a proper risk management by recommending better practices for operation and maintenance of the water supply system to reduce intermittency and to deal better with current IWS by end-users by reducing the water storage periods and adopting better hygiene practices (Step 6). The risk visualisation could also be designed to foster better communication between the water utility and end-users to strengthen trust relationships and better risk management (For example, survey results show 48.1% and 24.6% of water users are either agreeing or neutral when asked about the water company inspiring their trust).

Table 5. Qualitative description of the consequences of IWS according to MUISKA scales and dimensions

Scales → Dimensions ↓	Individual / Household	Community	River basin
Health and wellbeing	∗ Loss of free chlorine in stored and boiled water ∗ Increased potential of stored water contamination ∗ Increase / outbreak of excreta – related diseases ∗ Stress/ mental anguish because of death and sickness	∗ Increased health risks to end-users ∗ Stress/ mental anguish because of death and sickness	--
Infrastructure and associated services	∗ Air enters to the distribution network ∗ Sudden hydraulic changes occur ∗ Increased amount of pipe leaks ∗ People adopt storage behaviours ∗ Enforced use of alternative (safe and unsafe) water sources, e.g., bottled water, wells, surface sources ∗ People adopt additional water treatment processes: boiling, filtering	∗ Interruption of access to health services ∗ Water utility is no longer able to operate and maintain the water supply infrastructure	∗ Increased pressure on health services
Economy and productivity	∗ Increased costs of living because of additional water treatment ∗ Breakdown of productive activities in the home ∗ Interruption/ loss of employment ∗ Loss of income ∗ Interruption to education ∗ Termination of access to resources from the Colombian general participation system for not having the proper certification issued by the Superintendence of Public Utilities	∗ Open market of bottled water ∗ Discouragement of end-users from paying for water services ∗ Negatives impacts on the financial viability of the water utility ∗ Resources not available to improve service continuity and investment in infrastructure and subsidies.	
Ecosystem services	∗ Reduced water consumption supplied by the water utility	∗ Increased plastic waste	∗ Increased exploitation of aquifers

Scales → Dimensions ↓	Individual / Household	Community	River basin
		* Increased exploitation of other water sources	* Increased plastic waste. * Increased exploitation of other water sources
Culture, justice, and peace	* End-users distrust the water service * Families are in distress for sickness or death of relatives	* End-users distrust the water service * Communities are in distress for losing leaders, neighbours, and friends	--

5 CONCLUSION

In this paper, we indicated how to apply the approach MUISKA for a water-security risk: contamination of stored water in households because of an intermittent water supply system. This is an ongoing project of the Water Security and Sustainable Development Hub, and its scope covers other water-security hazards, such as droughts, floods, landslides, and poor water quality at basin level. MUISKA is based on stakeholder participation, systems perspective, and hydrocomplexity. Because of the multiple hazards and their impacts, MUISKA might be suitable for addressing complex and competing water-security scenarios.

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