A multi-dimensional approach to assess water-security risks in river basins

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1 ABSTRACT

The term water security was launched in 2000. 22 years have passed since then and the world is still experiencing high levels of water insecurity, and vulnerable communities and nations are the receptors of the most devastating consequences of such condition. Climate and socio-economic change can exacerbate water insecurity for all. To contribute to a better understanding of water-security risks in river basins, the authors of this paper present here an approach to assess water-security risks in five dimensions and four scales, and based on systems perspective, hydrocomplexity, risk science, participation of river basin relevant parties, and prioritisation process. Our proposed approach involves six steps: identification of the whole universe of water-security hazards for a specific river basin; qualitative description of the hazard impacts by scales and dimensions; prioritisation of impacts to be fully assessed; full risk assessment of prioritised impacts by analysis of hazards, exposure, vulnerabilities, uncertainties, and the strength of the knowledge; risk visualization; and outlining a risk management plan. We claim this approach could be useful for communities, organisations, academics, and practitioners dealing with or involved in water security. This is an ongoing project, and we are currently developing this approach in two municipalities in Colombia.

Keywords: dimensions, participation, prioritisation, risk assessment, scales, water security.

2 INTRODUCTION

The term "water security" became influential among researchers, policy makers, and development organizations after the World Water Forum (Ministers and Heads of Delegation, 2000), launched it in 2000 (Lautze and Manthrithilake, 2012). Early definitions of water security include properties such as multiscale (household to global), affordability (access), water safety (adequate quality and quantity), balanced uses for health and production, protection to vulnerable people from hazards and risks, protection to natural environment, political stability and peace, and sharing water resources properly (Global Water Partnership, 2000; Ministers and Heads of Delegation, 2000; Donoso et al., 2012; UN-Water, 2013).

To avoid that water security be utilised as an abstract concept in policy documents and development discourse, Lautze and Manthrithilake (2012) suggest that quantification of water security may offer a way to operationalise the term, and then reduce its ambiguity and promote deliberation on the scales, thresholds, and degree of water security. Thus, indexes and indicators have been the most developed tools to quantify water security (Lautze and Manthrithilake, 2012; Babel et al., 2020; Octavianti and Staddon, 2021).

However, we are far from achieving water security globally. Despite of multiple efforts to provide robust scientific evidence, create adequate policies, and provide enough funds to achieve water security, the current progress on six out of 11 indicators of the sustainable development goal No. 6 (SDG6) shows that global society is not on track yet of achieving this major aspiration (WHO et al., 2021; UN, 2021). According to the summary included in Figure 1, there is some progress on arrangements for international cooperation on transboundary basins, implementation of integrated water resources management, and access to safe services of water and sanitation. Nonetheless, the current rate is not enough to accomplish with universal access, and we are losing some water-related ecosystems, or their water quality is deteriorating (Figure 1).

6 CLEAN WATER AND SANITATION — 8 targets — 11 indicators

		Outcome	Notes
6.1.1 Proportion of population using safely managed drinking water services	2015-2020	9% basic drinking water 5% safely managed drinking water	*We are not on track of achieving SDG6. At the current rate, 1.6 billion people will be left without safely managed services by 2020.* *It is necessary to increase 4x in current rates of progress to achieve universal Access. [1] [2]*
6.1.2 Proportion of population using (a) safely managed drinking water services and (b) a hand washing facility with soap and water	2015-2020	7% no open defecation 4% basic Sanitation 4% safely managed Sanitation services 2% hygiene facilities	
6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	2015-2018	2% in sub regions from Africa and Asia	*[2]*
6.5.1 Degree of Integrated Water Resources management	2017-2020	5% global implementation	*[2]*
6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation	2020	128 out of 153 countries sharing transboundary basins submitted national reports on the status of their cooperative arrangements	*[2]*
6.6.1 Change in the extent of water-related ecosystems over time	2019	¼ of 2300 **lakes** assessed with poor water quality: high – extreme turbidity	*[2]*
	2019	More than 80% of **natural wetlands** loss since the preindustrial era	
	1970-2015	**Inland and marine / coastal wetlands** shrank by 35%	
	1996 - 2016	**Coastal mangroves** declined globally by 4.9%	

Figure 1. Progress on achievement of the sustainable development goal No. 6 (upward green arrow = increase | downward red arrow = decrease)

[1] (WHO et al., 2021) *[2]* (UN, 2021)

According to World Bank Group and (2017), US $112 billion are required annually to access to safely managed WASH services (targets 6.1 and 6.2 - SDG6). In general, efforts have been made to reduce inequalities. The United Nations report on progress in sustainable development goals (SDGs) (Economic and Social Council UN, 2021) informed that the official development assistance reached in total US $400 billion by 2019 for developing countries to achieve the SDG6. Similarly, official development assistance also increased funds for data and statistics from $591 million in 2015 to $693 million in 2018, as part of the SDG17 but there was not significant increase in 2019 (Economic and Social Council UN, 2021). The need for reliable data is increasing and the COVID-19 pandemic has aggravated crucial funding disparities in national, regional, and global statistical offices, increasing the urgency of the need to mobilize international and domestic resources in support of data for decision-making (Economic and Social Council UN, 2021).

In addition, climate change has consolidated globally, and it is not an abstract and distant phenomenon anymore because most people around the world are already observing or suffering its consequences (IPCC - Intergovernmental Panel on Climate Change, 2022a). According to the IPCC Assessment Report 6 (IPCC, 2022b), greenhouse gases emissions are still growing at high absolute rates; despite of growth has slowed in recent years. Additionally, current national promises under the Paris Agreement are insufficient to limit warming to 1.5°C and it is likely to limit warming to 2°C after 2030 if mitigation efforts are expended soon (IPCC, 2022b).

Climate change alone or in combination with other anthropogenic pressures have influenced water security. This is manifested 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 due to climate extremes, inland flooding, and flood or storm induced damages in coastal areas (Pörtner et al., 2022). With high confidence, the IPCC stated that, in the end, 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 cruel situation for millions of people in the world (Pörtner et al., 2022).

IPCC projections indicate that, without reduction of emissions, the previous consequences will worsen (high confidence) and regions and populations with higher exposure and vulnerability will face greater risks than others (medium confidence) (IPCC, 2022a). Particularly, climate risks are already manifesting in cities and settlements by the sea and will accelerate beyond 2050, and continue to escalate beyond 2100, even if warming stops (high confidence). One more alarming statement of the IPCC Working Group II is that cascading and transboundary risks will generate new and unexpected types of risks (high confidence). As a touch of hope, adaptation to climate change is already happening in natural and human systems but there are still gaps between the current adaptation state and the one needed for avoiding the increase of climate change consequences (IPCC, 2022a). In conclusion, much more financial resources are needed to achieve the SDGs, fund mitigation and adaptation actions for climate change, and monitor implementations and progress on both.

To adapt and mitigate successfully to global warming and other water-related hazards, it is important to bring together the risk science (Aven, 2020; Aven and Shital, 2022), knowledge and expertise of scholars from different disciplines (Hirsch Hadorn et al., 2006), systems thinking (Meadows, 2008), relevant parties participation (van Asselt, 2000), and hydrocomplexity (Kumar, 2015) approaches. We believe that these four factors together may foster the production of valid scientific outcomes to contribute to appropriate planning and decision making on water security for people and ecosystems. In line with this, there is a need of producing tools to assess risks that contribute to water and land planning, which could be accepted by relevant parties and decision makers if they were involved in the development process. Such tools must be suitable for scarce and uncertain data conditions, and scientifically valid. Therefore, we propose an approach called MUISKA (MUltidimensional rISK Assessment) to assessing and comparing multiple water-security risks at basin level. The underlying principle of the approach is to develop credible estimates of the relative risk burdens in five dimensions and four scales.

This paper aims to discuss the formulation of MUISKA by describing its conceptual framework and its potential application to different local contexts. The paper is organised as follows. First, we present the conceptual framework of MUISKA in section 3. Section 4 describes the approach structure. We discuss in section 5 the potential opportunities and challenges to develop MUISKA in general and to apply it in specific river basins. Finally, section 6 provides some conclusions and next steps.

3 CONCEPTUAL FRAMEWORK

3.1 WATER SECURITY

Several definitions of water security exist, and it is not our intention to discuss about the correctness of all or some of them. However, we want to highlight two definitions of water security, which are the foundations of the approach we present here:

1. "*Water security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, that the vulnerable are protected from the risks of water-related hazards while ensuring that the natural environment (freshwater, coastal and related ecosystems) is protected and political stability is promoted. Those using and sharing river basins and aquifers must manage their water sustainably, balancing water use for human development with protection of vital eco-systems and the ecological services they provide.*" (Global Water Partnership, 2000; Ministers and Heads of Delegation, 2000).
2. Water security is "*the capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards (floods, landslides, land subsidence, and droughts). Water security should be developed in a climate of peace and political stability.*" (Donoso et al., 2012; UN-Water, 2013).

The first step to put into action the term water security is accessing to data. However, sometimes data is inexistent, scarce, or unreliable (Butte et al., 2022; Laurien et al., 2022); then, quantification or operationalisation of water security is not always possible, and researchers and practitioners must create and adopt strategies to cope with such scenario. Institutions and organisations trying to achieve water security are probably finding that it is a difficult and expensive endeavour due to financial, technical, government, and governance limitations. As we mentioned previously, the term water security encompasses several key points such as access to safe and enough water with affordable costs, protection to vulnerable people from water-related hazards, ensuring protection for ecosystems and the services they offer, balancing water uses, and promotion of political stability. This necessarily leads to deal with a changing and uncertain climate, dynamic socio-economic global system, competing relevant parties' interests, and scarcity of resources (data, economic funds, human resources, etc.). 22 years have passed since the release on the term water security, and we have not yet achieved such state globally and enormous inequalities persist in most of the world. Therefore, it is crucial that decision makers have access to tools, which help them to make informed decisions about how to manage safely water-security risks to contribute to sustainable conditions for human beings and ecosystems to have a decent existence.

3.2 RISK ANALYSIS FOR WATER SECURITY

Risk analysis is a systematic process to comprehend the nature of risk and express it with the available knowledge. In a broader sense within the Society for Risk Analysis community, risk analysis includes risk assessment, characterisation, communication, management, and policy, in the context of risks concerning to individual, public, and private sector organisations, and to society at a local, regional, national, or global level (Society for Risk Analysis, 2018). The MUISKA approach focuses on risk assessment, communication, and explore risk management actions.

3.2.1 The concept of risk

Humans have worried about risks and tried to manage them since prehistoric times (Hansson and Aven, 2014). Risk is a concept commonly used by scholars and lay audiences and assessments are deeply intricate in human nature. Everybody assesses risks, either consciously or unconsciously before deciding. Risk can be defined in terms of probabilities of losing something of value and as a social construction. At the beginning, both approaches were presented as contraries, but it is accepted now that both can be true (van Asselt, 2000). In fact, under uncertain situations such as those posed by climate change, both approaches could be used complementarily for risk analysis.

Risk can be defined as "*the mental concept that exists when considering an activity in the future and involve two main features: i) values at stake (consequences with respect to something that humans value) and ii) uncertainties (what will the consequences be?)*" (Aven, 2020). Additionally, to produce a valid risk assessment, it is also necessary to include the judgements of the strength of the knowledge on consequences and uncertainties (Aven, 2020).

Additionally, van Asselt (2000) gave an operational definition of risk: risk should be logically sound; reflective of scientific expertise and public values; responsive to social concerns; and acceptable to experts, the public, and decision makers. In the rest of this paper, we will refer to water security risks, which are those originated from the water excess or scarcity and from poor water quality in river basins. For a practical definition of risk in the current approach, we adopt the concept of disaster risk to assess water-security risks in terms of hazards, exposure of people or assets, and their vulnerability (IPCC, 2012).

3.2.2 Risk assessment

Besides the consideration of hazards, exposure of people or assets, and their vulnerability, the risk analysis should also include the description of the temporal considerations, uncertainties, and judgement of the strength of the knowledge (Aven, 2020).

3.2.2.1 Hazards

Hazards are the risk sources where the potential consequences relate to harm (hazards) (Society for Risk Analysis, 2018), both in the past and the current situation of the basin/sub-basin. It also includes the situations that can lead to the presence of hazards or increase its impacts (hazardous events). Hazards and hazardous events can include water quality and quantity aspects, but also others identified in the specific contexts of river basin or sub-basins.

3.2.2.2 Exposure

Individuals, populations, infrastructure, or ecosystems can be exposed to the identified hazards and such exposure can vary depending on water use behaviours, location of such people and assets, and other social characteristics. Such elements can also be mapped to identify where the hazards or hazardous events are being (were) originated and where the risk is manifesting.

3.2.2.3 Vulnerabilities

Vulnerability refers to the weaknesses, attributes, causes, or lack of control of people, infrastructure, and ecosystems, exposed to a hazard, which would allow to those to cause harms (Función Pública, 2018). Vulnerabilities of individuals and populations can be characterised by age, social class, sexuality, disability, ethnic or religious background, marital status, or urban/rural setting, which could provide a detailed insight of the risk assessment and could help to understand better the distribution of risks (Myrttinen, 2018). One way to integrate different types of vulnerabilities could be by the creation of a vulnerability index, e.g., for flood risk assessment (Chakraborty et al., 2022).

3.2.2.4 Temporal considerations

To characterize appropriately the risks, it is important to clearly state the period when the hazards or hazardous events were observed, and the time considered evaluating the consequences of such hazards or hazardous events, after an event occurs (Logan et al., 2021).

3.2.2.5 Uncertainties

Emphasis on quantification has also been laid on risk components to calculate probabilities of hazards and vulnerabilities and then express their respective uncertainties. For risk assessments, it is necessary to identify the uncertainties associated with such occurrence, either if they were predicted by models or by other tools. Vulnerability descriptors can also have some associated uncertainties. However, because of complexity and systemic attributes of water systems, not all hazards, vulnerabilities and resulting risks can be characterised by probabilities. Therefore, qualitative descriptions of such uncertainties can also be included in the risk assessment to cover the whole universe of risks in a river basin.

How researchers communicate uncertainties is a crucial factor in water-related risk assessments, particularly when specialists try to make them in a collaborative, participatory, and transparent way with river basin relevant parties to create relationships of trust (Covitt and Anderson, 2022). Then, communication arises as another key component to identify and prioritise risks, and decision makers must be aware of risk perceptions from exposed populations to hazards to create policies and allocate funds for risk management.

3.2.2.6 Judgement of strength of the knowledge of uncertainties

Any judgement of uncertainty is based on some knowledge, which can be more or less strong. According to Aven (2020), the judgement of the strength of the knowledge can be reported by three scales (weak, medium, and strong) based on the assumptions, data availability, disagreement among experts, understanding of the phenomena involved, and knowledge available (unknown knowns).

3.3 SYSTEMS THINKING AND HYDROCOMPLEXITY

Water-security risks should be approached from the system thinking theory (Meadows, 2008) since a water system could be conceived as a system with natural and manmade structures; functions such as support, provision, regulation, and culture; and interactions among its components (Haileslassie et al., 2020). Besides, 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 at a range of scales and sectors. 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 hydrocomplexity. Hydrocomplexity is "*an integrated approach, aimed at taking a broad contextual view of water in all its complexity to seek out principles and methodologies to unravel the interactions across hydrosphere, biosphere, atmosphere, cryosphere, lithosphere, and anthroposphere*" (Kumar, 2015).

Due to the hydrocomplexity of water systems, it is important to define systemic risks associated with complex systems. Thus, we use the definition offered by Renn and co-authors. A systemic risk must meet the following conditions: high complexity with respect to causal or functional relationships (no linear cause-effect relationship but multiples negative and positive feedback loops instead), multiple uncertainties, being associated with cascading impacts within the scale in which the risk is located and beyond this scale, and major ambiguities (Renn et al., 2020). Schweizer et al. (2021) also states that systemic risks are characterised by high dependency on contextual factors.

Additionally, Kumar (2015) also offered key characteristics of emergent risks (or black swans) associated particularly with water systems: i) causes and effects are separated in time and space; ii) interdisciplinarity is needed to develop effective approaches to hydrocomplexity; iii) there are high uncertainties about the proper solutions leading to desired outcomes; iv) new hazards or risks can be created when a new solution layer is built on top of existing layers, which generates novel dependencies in the water system; and v) it is not easy to find trade-offs for solution options due to complex societal values.

4 MUISKA: A MULTIDIMENSIONAL APPROACH

According to the conceptual framework presented in the section 3 of this paper, we propose the approach MUISKA for assessing and comparing multiple water-security risks simplifying the nature of risks but pursuing to keep the universe of potential risks as wide as possible, looking across the whole basin, but prioritising areas for actions. We have excluded major transboundary issues since they usually lie outside of the people's scope who live within the river basins. This approach also incorporates space and time considerations. The former is related to where the hazard is originated and where the risk is manifesting. For the later, the risk assessment must clarify the time frame set for when the hazards were observed, and the time considered evaluating the consequences of such hazardous events (Logan et al., 2021). In the MUISKA approach we therefore propose:

1. Four general scales of risk: country, basin, community, and individual/ household.

2. Five dimensions where impacts can occur: health and wellbeing, infrastructure and associated services, economy and productivity, ecosystem services, and culture, justice, and peace.

Our general approach has six steps (Figure 2). MUISKA includes two consultation processes (steps 3 and 6), which will need the application of a decision analysis tool or technique to compare, discuss, and agree to priorities according to their values and the power relationships among relevant parties. Such tool must allow the consideration of the voices of those who are not usually included equitably in risk management decisions and who might be the receptors of serious water-insecurity consequences (Fletcher et al., 2022). The step 4 is about the full risk assessment of the prioritised impacts according to the hazard, exposure, vulnerabilities, uncertainties, and strength of the knowledge (Aven, 2020). Once the risk management plan is outlined, researchers must review the proposed interventions to identify potential creation of new hazards or risks or increase the current level of risks in the river basin.

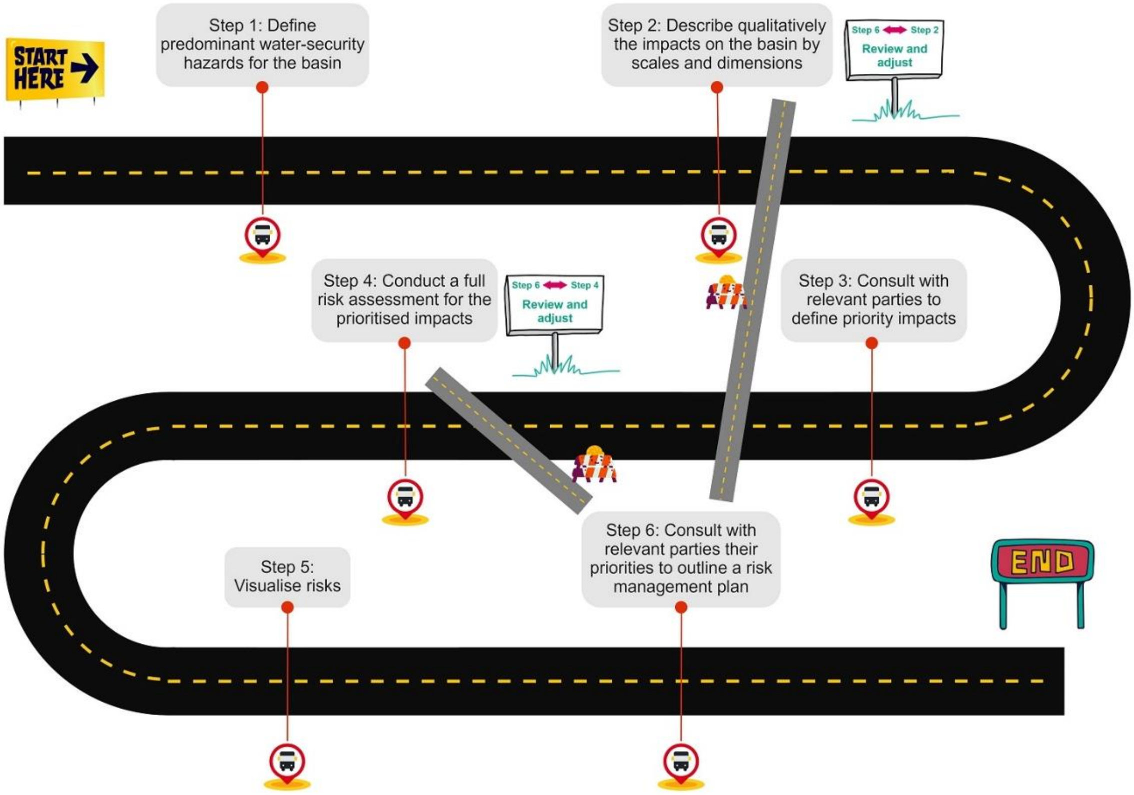

Figure 2. Schematic representation of the process proposed in MUISKA

Based on the work of Tonmoy et al. (2019), we describe in **¡Error! La autoreferencia al marcador no es válida.** the objectives, requirements of base knowledge, level of engagement, and the expected outcomes of each step of MUISKA. We added a preliminary step to identify the relevant parties in the river basin where this approach will be applied to invite to take part of its development in a specific context.

Table 1. Characteristics and requirements of each step of MUISKA

MUISKA step	Objectives	Base knowledge requirement	Expected outcomes
Step 0: Analysis of	Identify the relevant parties in the river basin to	Local knowledge required to identify the	List of river basin relevant parties and their

MUISKA step	Objectives	Base knowledge requirement	Expected outcomes
relevant parties	be invited to take part in the current research project. Identify the relevant parties' interest, influence, and impact in/on/from the current research project (Reed et al., 2023).	relevant parties in river basins and their interest, influence, and impact in/on/from the current research project.	classification by several categories according to their interest, influence, and impact in/on/from the current research project.
Step 1: Define predominant hazards for the basin	Develop a quick high-level understanding of the water-security hazards in the river basin.	Local knowledge required to identify hazards and their history.	Identified water uses in the river basin. List of predominant hazards in the river basin, categorised according to water quantity or quality, and the location where hazards are originated.
Step 2: Qualitative description of the impacts of hazards on the basin	Create a network of hazards and their consequences and identification of how basin subsystems are interrelated. Identify interdisciplinarity cooperation needs and promote systems thinking.	Local knowledge required to construct the network of hazards and their consequences.	List of problems/conflicts created from water uses. Network of hazards and their consequences and identification of how they are interrelated (feedback loops). Classification of impacts according to scales and dimensions proposed by MUISKA (risk matrices).
Step 3: Consult to define priority impacts	Define, by relevant parties, priority impacts of hazards by dimensions and scales. Recognise values associated with prioritisation of impacts. Recognise power relationships influencing the prioritisation.	Active involvement of relevant parties is required to consult the priority impacts in the river basin.	List of prioritised impacts by each relevant party, together with water values and power influences. Identified ambiguities, divergences in judgements or disagreements among relevant parties.
Step 4: Assess the risk of the prioritised impacts	Assess the risks of the prioritised impacts either quantitatively, qualitatively, or by a combination of both. Identify opportunities to create a general risk indicator or alternative ways to visualise / communicate risks by dimensions and scales.	Local knowledge required to define vulnerabilities. High expertise required to gain specific data (may not be necessary for all impacts).	Description of time and space considerations included in the assessment. List of risks by dimensions and scales classified by categories. Acknowledgement and description of uncertainties and strength of the knowledge.

MUISKA step	Objectives	Base knowledge requirement	Expected outcomes
Step 5: Visualise risks	Communicate the results of the risk assessment to relevant parties, academics, and general audiences.	Local knowledge required to get participants' feedback on risk communication.	Several of the following: matrices, maps, spider charts, lollipop graphs, Sanky diagrams, infographics, etc.
Step 6: Outline a risk management plan	Provide a general guideline for risk management, including determination of research gaps associated with uncertain risks. Recognise values and power relationships influencing the preferred actions and interventions. Identify ambiguities within group of relevant parties in relation to prioritised impacts and preferred actions and interventions.	Active involvement of relevant parties is required to consult actions and interventions.	Concerted guidelines for water-security risk management for the river basin. Identified relationships among water values, level of influence or power, and prioritised actions for risk management. Determination of the consequences of risk management actions in relation to the creation of new risks or hazards or exacerbation of the existing ones. Identified ambiguities, divergences in judgements or disagreements among relevant parties.

4.1 SCALES AND DIMENSIONS

We propose to characterise risks according to four scales and five dimensions. Water-security risks can materialise at different scales, i.e., to individual or country levels. The scale of a risk refers to the extent to which it is felt and could potentially be mitigated by individuals/households, compared to those which are felt at basin level or across society. In the latter case, individual or community actions are unlikely to mitigate the effects, and responses need to be organised by the state or at basin level (usually in the form of infrastructure or economic adjustments to water management practices or economic activities such as irrigation). At the level of individuals/households, we might also consider impacts that spread around the community (for example outbreaks of water borne diseases) and their control lies outside the individuals/households.

The previous was stablished considering that the concept of water security operates at all levels, from individual, household, and community, to local, sub-national, national, regional, and international settings (UN-Water, 2013). Similarly, risks, once have been originated, may cascade from an individual or household level to societal level (Kumar, 2015; Renn et al., 2020; Simpson et al., 2021).

On the other hand, such risks expressed in one or more scales can also be classified by dimensions, such as health and wellbeing, infrastructure and associated services, economy and productivity, ecosystem services, and culture, justice, and peace. These were established considering that many factors, from biophysical to infrastructural, institutional, political, social, and financial elements are involved in water security (Donoso et al., 2012; UN-Water, 2013).

Some approaches focus on the aquatic system (or the hydrologic/hydraulic system) to deal with the biophysical impacts, and some like integrated water resource management (IWRM) often take a more econometric approach (so focus on financial, social, political factors) (Global Water Partnership, 2018), but consideration for the actual assets themselves - the infrastructure - is still missing, particularly for the conceptualisation of water security that observes infrastructure (Octavianti and Charles, 2019). In line with this, our proposal includes the infrastructure dimension because risk manifestation in the infrastructure can cascade into other sectors at several scales, in the short, mid, or long term.

Recently, the IPCC in its 6th Assessment Report for Climate Change (IPCC, 2022b) included recent advances for the first time in mitigation knowledge across sectors and systems such as energy, urban and other settlements, transport, buildings, industry, and agriculture, forestry and other land use and cross-sectoral perspectives. In general, our hypothesis is that different risk in certain dimensions and scales could be different from those manifesting at other scales and dimensions. For example, individuals / households will face risks related to mainly the dimensions health and wellbeing and infrastructure and associated services. As the scale size changes, the distribution of the impacts also changes. Thus, impacts on economy and productivity and ecosystem services might be more severe at country scale. To confirm this, we must develop the current approach in a river basin to determine the risk distribution by scales and dimensions, which is out of the scope of the current paper. However, this is an ongoing project, then we are developing MUISKA in two locations at the Upper Cauca River Basin in Colombia and we will publish the results in due course. In the meantime, we expect this paper steer a fruitful conversation among risk scientists and practitioners.

4.2 PRIORITISATION

The general process we are proposing with MUISKA includes two prioritisation steps (Figure 2). The step 3 is about consultation with relevant parties (step 0) to prioritise the consequences of hazards, which will be fully assessed to determine their risks. The step 6 is also about consultation with relevant parties (step 0) to identify priority interventions to outline a risk management plan. Both steps will allow us to establish the water values associated with the relevant parties' priorities, and ambiguities and disagreements between members of the same group of relevant parties or even between relevant parties. An important point for prioritisation in MUISKA is the method used to define such priorities, which should reduce the researcher and participants' biases, do not favour interests from particular relevant parties based on their power or level of influence, and support the expression of those people who are not usually included in risk assessments and decision making for risk management in a specific context (Fletcher et al., 2022).

Several methods or tools exist for decision making, which could be as simple as multi-voting (American Society for Quality, 2022) or a more quantitative one such as multicriteria analysis (Elshorbagy et al., 2007). Every method has advantages and disadvantages and the choice of the most appropriate one must correspond to the local context and the objective to be achieved. Thus, we anticipate that one way to address this challenge might be the combination of two or more methods. The next phase of this work will allow us to better define this.

4.3 RISK COMMUNICATION

Risk communication is a crucial component of the whole process of risk analysis. Given that valid risks assessment must involve relevant parties and that risk management includes directly communicating the results of the assessment to those who may be affected by the water-security risks identified in a specific river basin, risk communication must include reporting uncertainty, understanding risk perceptions, deciding on interventions to manage risks, and implementation of such interventions. Additionally, the risk analysis might be dynamic to be updated by relevant parties when initial conditions change.

Despite of communication must be done in a language that all parties can understand, scientists and risk analysts must be careful to not oversimplify the message to the point that the audience assume that the hazards, vulnerabilities, or risks are more certain than they are actually (Rennie, 2020). On the other hand, uncertainty of hazards, vulnerabilities and risks might be used to show water-related risk assessments as a scientific field with a set of unanswered questions open to debate and more research. Therefore, it may be constructed participatorily for the specific contexts, opening communication channels among relevant parties, and fostering closer relationships (Rabinovich and Morton, 2012). The step 5 in MUISKA (Figure 2) involves the creation of visualization products to communicate the results of the risk assessment obtained in the step 4. These products will be shown to participants in our study to understand whether such images are communicating properly the water-security risks in a specific river basin.

5 DISCUSSION OF OPPORTUNITIES AND CHALLENGES

In this paper, we are introducing an approach to assess water-security risks in five dimensions and four scales, at basin level. The foundations of MUISKA are water security, risk science, systems perspective, hydrocomplexity, prioritisation, and the participation of river basin relevant parties. We propose MUISKA as an intermediate approach between global, general, and rough approaches and more local, specific, and detailed ones to evaluate the whole universe of water-security risks in specific contexts by the inclusion and participation of relevant parties (Figure 3).

Figure 3. MUISKA as an intermediate approach

Our intention is that MUISKA can be accepted by water-security risk scientist and practitioners and then adapted to specific and local conditions of any river basin by adjusting the social and engineering methods in each of the steps presented here (Table 1). We believe that MUISKA could be an alternative to handle the complexity of achieving water security with limited resources because people and institutions involved in water usage and management, by its application, could increase their awareness of the existing of the entire universe of water-security hazards, their consequences, and the interconnections among the elements of the water system. Besides, the application of MUISKA might encourage discussions and agreements to prioritise the consequences which must be fully assessed and the risk management interventions, according to the impact scale of such risks, the resources available and other criteria. Alternatively, the development of MUISKA may also help to identify ambiguities and disagreements among relevant parties, which must be addressed to continue with the risk assessments and formulation of the management plan.

The recent work done by Niggli et al. (2022) also incorporates systems perspective, cascading risks, and multi-sector analysis (here dimensions) to understand better the impacts of historical droughts and heat extreme events in Europe, Africa, and Australia. These authors provide qualitative and quantitative information to describe such impacts and present a network of interconnectedness of systems, sectors, and assets. This allowed them to identify the sectors or assets being affected mostly by those extreme events and to suggest response measures and adaptation policies for such sectors and assets (Niggli et al., 2022).

Similarly, One Health is an approach of the World Health Organisation launched recently (WHO Regional Office for Europe, 2022; FAO et al., 2022). It acknowledges the need to study health as linked to the interfaces between humans, animals, plants, and the environment with an interdisciplinary perspective. Our work presented here aligns with such recent approaches to global and complex problems by incorporating analysis in multiple dimensions to offer more detailed information of the distribution of environmental risks. Also, this proposed approach also responds partially to other researchers claims (e.g., Laurien et al. (2022)), who advocate for incorporating mixed methods (qualitative and quantitative), customizability, adaptability to specific contexts, analysis of compound risks, and multiple vulnerabilities to assess better resilience to climate-related disasters.

The participation of relevant parties is needed to carry out collectively the risk analysis. While researchers can act as guides or facilitators, relevant parties provide local knowledge about hazard consequences, and the interrelations among the different components of the water system (van Asselt, 2000). Besides, participatory methods can help to expose their risk perceptions, priorities, water values, and interests. All of these are necessary for the risk assessment of their prioritised consequences and to outline a risk management plan. We also consider MUISKA as a dynamic process, which could be iterative to be reviewed and adjusted according to the dynamics of global drivers of change such as climate and socio-economic change. Through the participation of relevant parties in this research, they can take ownership of the risk analysis process to adjust it if the initial physical and government conditions changed in the river basin (Laurien et al., 2022).

Since the step 4 of MUISKA is not exclusively tied to quantitative risk assessments, our approach gives space to qualitative assessments to complement quantitative results or to describe fully the risks in case that data is insufficient, not available, highly uncertain, or not reliable. Also, this helps to identify research gaps to gather more and better information for further risk assessments and possibly with collaboration between academics, communities, and organisations.

Despite of the potential benefits that the application of our approach might have, we are aware that this paper presents only the conceptual formulation of MUISKA, and we must provide evidence of the outcomes produced by its application in a real river basin. To achieve this, we are currently developing this approach in two municipalities at the UCRB in Colombia, where two institutional partners are researching different aspects of water security as part of the international project Water Security and Sustainable Development Hub (Water Security and Sustainable Development Hub, 2019).

On the other hand, the step 4 of our approach represents a challenge related to the way risk is going to be expressed in each of the five dimensions proposed here: health and wellbeing, infrastructure and associated services, economy and productivity, ecosystem services, and culture, justice, and peace. This challenge is opening new research questions which must be answered to successfully develop MUISKA in real case studies. Such questions are:

* What are the metrics or indicators used by researchers and national agencies to express risk associated with water security in the dimensions included in the approach MUISKA?
* Could a single or standard metric be created to express water-security risks in all the dimensions included in the approach MUISKA?
* Or there must be a specific indicator or metric to express risks in each dimension?
* If the previous question is responded positively, how do we compare risks in each dimension and guide to the river basin relevant parties to prioritise risk management actions?

Similarly, we anticipate potential challenges during the application of MUISKA in real case studies such as securing the participation of all relevant river basin relevant parties to take part in this research. Also, we believe that the research team must spent time in the river basin to interact with leaders, communities, and employees of key organisations to build trust and ease the development of the study. Although we do not have yet conclusive results of the application of this approach in real case studies, we believe it is important to present it to the academic community to open a discussion regarding the difficulties of achieving water security, particularly in locations where resources of all kinds are limited, and the alternatives this community can propose to tackle this problem.

6 CONCLUSION

Communities, organisations, academics, and practitioners dealing with or involved in water security would benefit from an approach, which might help them to identify the whole universe of water-security hazards, their consequences, and the interrelationships existing among the different elements of the water system. Thus, we presented our approach called MUISKA in this paper. MUISKA also includes the prioritisation, by river basin relevant parties, of the hazard impacts to be fully assessed and to define risk management actions, according to the impact scale of such risks, the availability of economic funds, among other criteria.

To demonstrate the potential benefits of our approach, which we describe in this paper, we must apply it in real case studies. This may also lead to further adjustments of MUISKA to maximise its positive impact in communities and the water sector in general. We also reflected on how the results of the risk assessment (step 4 - Figure 2 and Table 1) is going to be expressed for each of the five dimensions proposed here. Finally, we also highlighted the importance of trust building between researchers and practitioners, who could be willing to apply this approach on specific contexts, and river basin relevant parties before start fully with the application of MUISKA.

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