Joint Publication

CLIMATE RESILIENT WATER RESOURCES MANAGEMENT

Driving the Conversation Forward

In collaboration with

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Foreword

Globally, the effects of climate change are already being felt with rising temperatures, droughts, and heatwaves as well as more frequent and severe storm events impacting water quantity and water quality. As such, water managers at all levels of governance, from the city to transboundary river basin level, need to ensure communities are resilient to water scarcity pressures as well as water excesses, all the while ensuring the natural system and its associated ecosystem services are protected and enhanced. In this context, a community that is resilient to climatic extremes is one that is reflective (learns from experiences), robust (people and infrastructure can withstand the impacts of extreme conditions), forward-thinking (plans are made to ensure systems function in extreme conditions), flexible (systems and plans can change), inclusive (all stakeholders are involved in planning), and integrated (people, systems, decisions, investments, etc. are mutually supportive of common goals). There is, however, no single action or strategy that any government— city, state, nation, or transboundary organisation—can implement to ensure a community is resilient to climate change-related extreme weather events while protecting the natural system. Instead, climate resilient water resources management requires integrated, forward-thinking policies, practices, and technologies that not only are adaptable to changing climatic conditions but also seek to maximise economic and social welfare in an equitable manner while ensuring the health of ecosystems.

Robert C Brears

Robert C. Brears
Founder of Our Future Water

Foreword

The Water and Climate Coalition (WCC) pursues actions established to promote climate-resilient water resources management. Essential to successfully managing water resources in a changing climate is the acquisition and dissemination of salient water information to guide decision-making and policy-making processes, combined with an alignment of the climate and water agenda to maximise coherent and integrated action. Both these endeavours represent the two focus themes for this publication and are prime objectives of the WCC.

The WCC is an action-oriented community founded under the banner of the SDG 6 Global Acceleration Framework and engineered to equip multi-sectoral stakeholders with a platform enabling the attainment of interlinked SDG 6 and SDG 13 targets. WMO co-founded the WCC together with nine other UN entities and the Global Water Partnership (GWP) as a multistakeholder initiative, and it now has more than 160 institutional members committed to accelerating the implementation of integrated water and climate activities.

Ensuring resilient water-adaption in the face of climate change is a foremost example of the integrated climate and water targets the WCC seeks to achieve. In the build-up to COP27 and during the conference itself, the water agenda must not be submerged under a deluge of climate-focused dialogues - but instead act in unison with the climate agenda for effective hand-in-hand consideration at the discussion table. To contribute to this objective, the WCC has mobilised its diverse Member base - possessing disparate skills and expertise - to jointly deliver this publication showcasing a variety of multi-scale climate-resilient water resources management pursuits. In the months preceding the UN 2023 Water Conference, where the water agenda is primed to generate the largest ripples in almost fifty years, it is of paramount importance that the impetus behind this vital agenda remains stimulated and maintained. The following articles provide ignition to that end.

S. Uhlenbrook

Stefan Uhlenbrook
Director of the WCC Secretariat,
September 2022 onwards

Johannes Cullmann

Johannes Cullmann
Director of the WCC Secretariat,
March 2021 till June 2022

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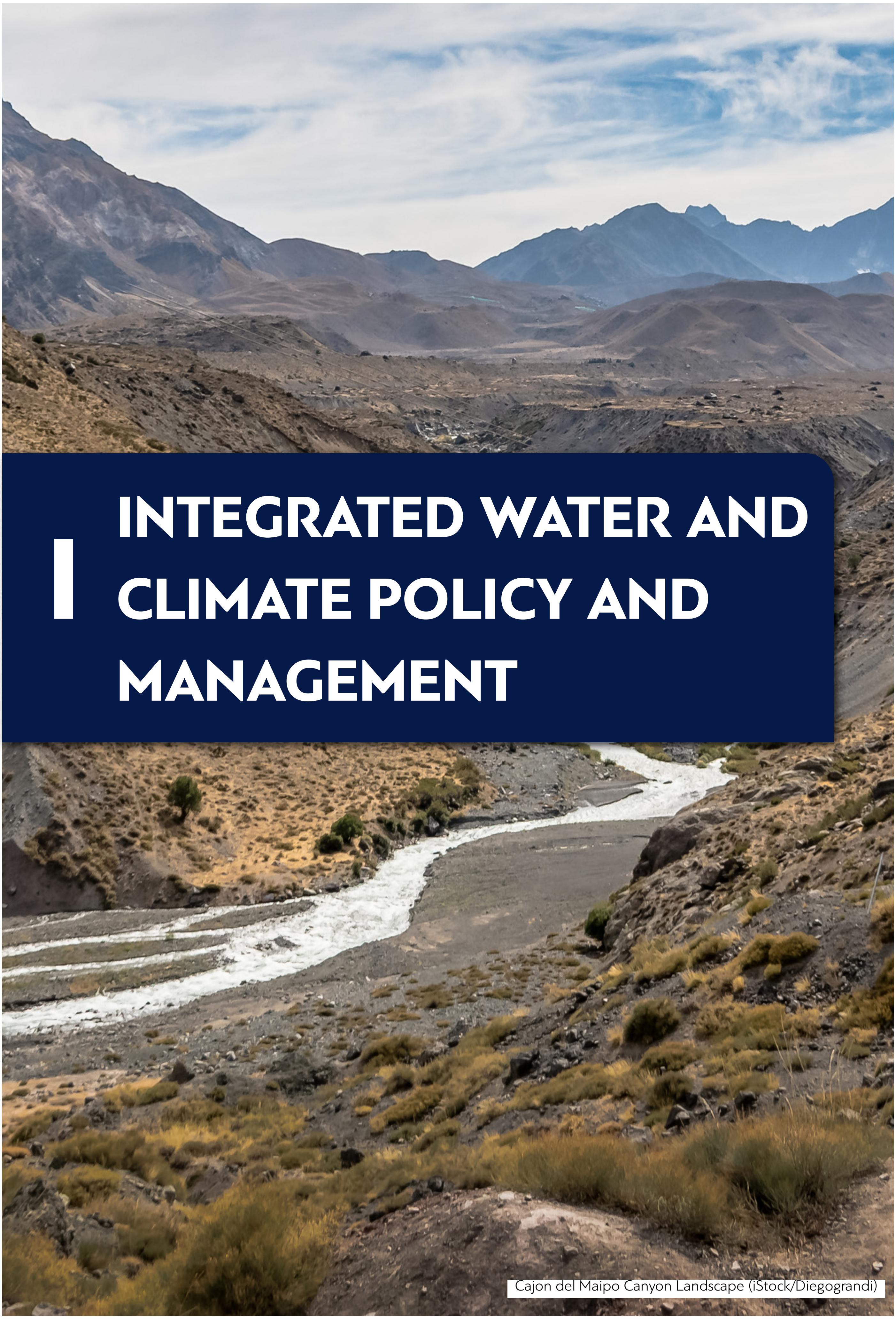
I INTEGRATED WATER AND CLIMATE POLICY AND MANAGEMENT



Cajon del Maipo Canyon Landscape (iStock/Diegograndi)

1. RDM as a Methodological Tool for Intervention Strategy Definition in Two Central Chile's Basins

Felipe de la Hoz M, Diego Rivera S, Daniela Latoja V, Lorenzo Cigarra G., Edmundo Molina P, Raúl Muñoz C

Background:

To inform and support water security planning at basin level in Chile[1], the Interamerican Development Bank (IADB) promoted research actions by piloting participatory bottom-up approaches to assess robustness of potential adaptation paths under climate, environmental and societal related uncertainties. More specifically, one of the pursuits of these research projects was to define and prioritize robust local intervention strategies against high uncertainty scenarios due to climate change and variability.

Methodology:

The Robust Decision Making (RDM) methodology was applied in two main basins of central Chile to assess robustness of different climate adaptation strategies to inform water security planning in both systems.. These two basins have different hydrological conditions, demography, and productive development. These conditions determine the gap between water supply and water demand in each basin and territorial water conflicts and their participants. Such conflicts were identified and characterized in previous initiatives, which allowed to construct a problem tree for each basin. Based on this, it was possible to explore Action Strategies (AS; view Table 1) that might help solve each problem of problem tree. Having defined the set of AS for each basin, an implementation upper limit for each AS was determined, in terms of its water volume contribution/saving and the economic investment required, given the territories' features and information.

It was identified that the core of the problems corresponds to lack of security and uncertainty on the sustainability of water resources. Therefore, advancement toward water security and sustainability was proposed as a solution. Considering this, a XLRM matrix was created (Table 2), which summarises the goals pursued, the tools that allow the verification of the achievement of those goals, and the AS and uncertainties involved in the process. For the present work, a 'water security index' (WSI) was defined as a performance measure as well as an intervention strategy cost-benefit analysis. In this case, the AS being assessed considered strategies associated with water efficiency and targeted use of water resources. The models used to simulate different scenarios and the effect of AS on water availability were HydroBID and MODSIM, both integrated in WaterAlloc. To reduce total computing/simulation times, a simplified model in R (for MODSIM) was implemented, which represented waterflow relationships along the basin. Uncertainties considered were: current and projected water demand and supply, climate, AS' implementation tops and levels, timing of AS' intervention levels, and required economic resources.

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[1] For the purpose of this academic exercise the names of the pilot basins are kept as confidential.

MODSIM) was implemented, which represented waterflow relationships along the basin. Uncertainties considered were: current and projected water demand and supply, climate, AS' implementation tops and levels, timing of AS' intervention levels, and required economic resources.

Table 1. List of AS by strategic action line.

Strategic action lines / AS groups	Action Strategies (AS)
Conduction improvement	Reconstruction and improvement of irrigation canals to reduce infiltration losses
	Closed water conduction.
	Impervious concrete lining to reduce infiltration losses.
Storage	Polypropylene drainage cells for rainwater management
	ADS StormTech® cameras for rainwater management
Water use optimization	Drip irrigation for green spaces and urban areas (85%).
	Underground irrigation for green spaces (90%).
	Major mechanized irrigation (aspersion or similar) (75%)
	Localized micro irrigation (drip, microaspersion, microjet, or similar) (85%).
	Underground irrigation for agriculture (90%).
Demand reduction	Crop covers to increase moisture retention in crops.
	Agricultural conversion to lower water requirements crops.
	Hydroponic and aeroponic crops.
	Vertical agriculture in greenhouses.
	Xeric or low water requirement landscaping.
	Vegetation change to native/lower water requirement species in urban green spaces.
	Mulch for water retention in soil for xeric landscaping
	Hydrogel in roots to reduce water use for irrigation of green spaces.
	Hydrogel in roots to reduce water use for irrigation.
	Toilet-sink combo to reduce water consumption.
	Lower water requirement sanitary systems.
	Rinse-free laundry detergent.
	Waterless car wash.
	Foam soap for hand washing.

Strategic action lines / AS groups	Action Strategies (AS)
Water management optimization	Precision agriculture using regulated deficit irrigation techniques.
	Temperature regulation devices for increased efficiency in warm water consumption.
	Mobile apps for efficient management of domestic water consumption
Process change	Zero or minimum conservation tillage; permaculture for agricultural production or agroforestry.
Treatment	Superficial artificial wetlands
	Wastewater treatment using activated sludge.
	Subsuperficial artificial wetlands.
	Vermifilter for wastewater treatment.
	Biofilter for wastewater treatment.
	Coagulation and flocculation for wastewater treatment.
Reuse	Urban wastewater reuse in submarine outfalls.
	Rural wastewater reuse.

Table 2. XRLM matrix constructed for the present problem.

(X) Uncertainties	(L) Policy levers or strategies
- Current and projected water demand. - Current and projected water supply. - Climate. - AS' implementation tops and levels. - Timing of AS' intervention levels. - Required economic resources	- AS' implementation on the territories (water efficiency and strategic use of water resources)
(R) Models or relationships	**(M) Performance metrics or measures**
- HydroBID - MODSIM (simplified in R)	- Water safety index - Cost-benefit of intervention strategies

To assess the effect of intervention strategies, the same fluviometric stations that were utilized in the HydroBID calibration process were used in the present work. Each one of these stations represents an upstream influence area and conditionate AS' implementation roof. Subsequently, a matrix of combinations was developed, including repetition and three implementation levels to AS' implementation maximum values (0%, 50%, and 100%) spatially distributed in each station. The set of AS considered could be classified by strategic action lines, such as 'conduction improvement', 'storage and optimization of water use', 'demand reduction', 'optimization of water management', and 'process change, treatment, and reuse'. A run on the simplified model was required for each basin and AS combination, adding up to 6561 of AS combinations for each basin (8 AS groups and 36 AS in each basin).

Climate uncertainty was considered by utilizing nine climate scenarios, the first being the RCP8.5 scenario (base scenario). The rest of the eight scenarios were created by applying temperature and precipitation variations upon the base scenario, resulting in different warmer/colder or drier/wetter scenarios than the base one. Each of the 6561 AS combinations was run as an individual simulation on each scenario, which implied a total simulation count of 59049 runs.

The most robust AS combinations were identified by calculating the WSI for the year 2050, on a monthly time scale, for each run, station, and basin and comparing it with the value on the corresponding control run (no AS applied). This was performed using all nine climate scenarios independently. In the first basin (A), some stations show unfavourable hydrological conditions throughout the entire year. In the second basin (B), critical conditions arise only during summer. The former implies differentiated solutions: in basin (A), there is a need to increase available water volumes throughout the year, and in basin (B), redistribution of water sources and uses throughout the year could be enough.

A criterion was defined for an intervention strategy to be considered as robust and therefore selected for further analysis. This criterion indicates that a robust strategy should increase WSI's value by a statistically significant amount, which was calculated as the difference between the WSI's value on the base scenario and the 25th percentile of the set of nine WSI values on all climate scenarios. This was calculated for the year 2050 on a monthly scale and for each station and basin. Results showed that no strategy could meet the criterion for all months and stations in each basin. Therefore, strategies that met the criterion for the highest number of months and stations within a basin were considered as robust.

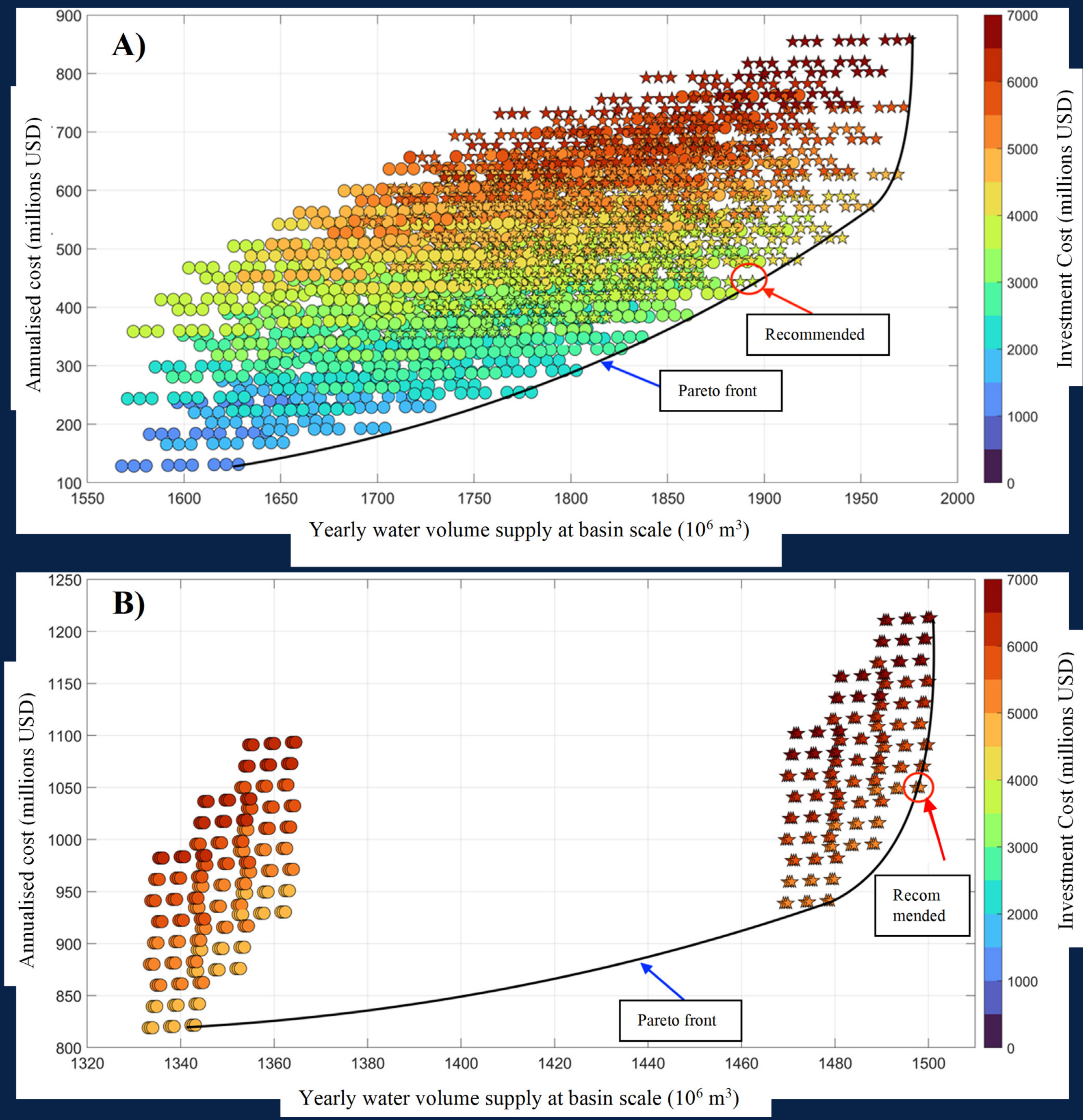
The final selection of strategies was performed by doing a cost-benefit analysis, which allowed to recognize the best strategies in terms of water volume supply – investment costs – lifespan (Pareto front). Combined with the former criteria, this analysis allowed to identify those strategies on/ around the Pareto front (Figure 1).

Results and conclusions:

For the first basin case (Figure 1A), the best intervention strategy has an investment cost of $3882. Five million USD and a water volume supply of 1893.9 MMm3/year. It considered the following strategic action lines: conduction improvement, water use optimization, demand reduction, process change and treatment.

For the second basin case (Figure 1B), the best AS combination showed investment costs of $5.334,8 million USD and a water volume supply of 1498 MMm3/year. The strategy considered the following strategic action lines: water use optimization, demand reduction, water management optimization, process change, treatment, and reuse.

Figure 1. (below) Representation of AS combinations that provide the greatest water volume supply in the basin (A) and basin (B) v/s annualized cost (vertical axes) and implementation investment cost (colour scale). ★symbols indicate the AS combinations that meet the criteria of statistically significant water volume supply in the highest number of months and stations. The solid black line indicates the Pareto front.



2. Climate Resilient Transboundary Water Management: Data-Driven, Internationally Shared, and Community-Accessible Modelling of Coupled Human and Natural Systems

Sam Fernald, Ashley Atkins, Christine Kirkpatrick, Ilya Zaslavsky, Saeed Langarudi

Transboundary aquifers serve as critical yet understudied global freshwater resources. Reductions in surface water availability, exacerbated by climate change, have led to intensified groundwater depletion that threatens the sustainability of transboundary water and the interconnected systems that rely on these supplies. In light of these environmental realities, water management challenges are intensified for transboundary aquifers because these resources are shared between communities with often disparate hydrologic understandings and decision-making structures. Disciplinary work dominates transboundary groundwater research; transboundary groundwater problems, however, are highly complex and do not fall entirely within the scope of any single discipline. The extensive focus on the legal framework for international waters has been useful for measurable and tangible surface water, but these successes have not been replicated when applied to groundwater. While existing disciplinary research approaches have provided important initial findings about transboundary water, the lack of convergence has been detrimental to fully understanding these resources and the implications of potential management decisions within complex coupled human and natural systems. Resilient water management necessitates the mitigation of unintended decision-making consequences. Convergent analysis that can reflect the complexity of coupled natural and human transboundary systems is essential to avoiding maladaptation in the face of climate change.

In response to these challenges, our team formed the National Science Foundation-funded Transboundary Groundwater Resiliency Research (TGRR) Network-of-Networks, which connects hydrology, social science, data science, and systems science communities. The goals of TGRR are to 1) catalyze transboundary groundwater resilience research to address groundwater scarcity and its natural and societal impacts, 2) identify the capabilities of the convergence approach to determine key questions and fill critical gaps in knowledge and resources, and 3) support the development of students and early-career researchers who will lead the next generation to collaboratively integrate water, data, and systems sciences to address transboundary groundwater scarcity.

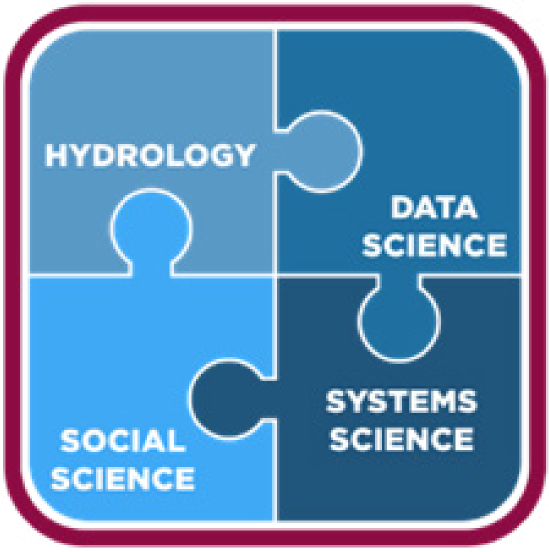


Figure 1. Integrated disciplines for the [Transboundary Groundwater Resiliency Research (TGRR) Network-of-Networks]()

Conclusion

Our work is already showing promise to innovatively lead to an improved understanding of transboundary aquifer systems. We have held over ten conversations, lectures, and workshops to broaden our network and have had success building the convergence of our four primary disciplines. In addition, we have a strong student and early-career researcher cohort to provide leadership opportunities for the next generation of researchers. As an illustration of this progress, we presented the work as an activity of the Water and Climate Coalition. As a result, we received invaluable input regarding concurrent binational development of shared human and hydrologic systems models to understand and act on climate resilient water adaptation. We are already implementing this internationally-shared system modelling for community water understanding as part of our detailed activities on the U.S.-Mexico border. We look forward to engaging the climate adaptation community to develop further our approach to water management that avoids unintended consequences of maladaptive responses to climate change.

Funding acknowledgement:

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Lake Mead behind Hoover; water line visible (Getty Images Signature/csreed)

3. Learning From European Floods 2021 Towards Resilience-Focused Recovery Pathways

Flood Risk Governance To Facilitate Climate-Resilient Pathways

Nidhi Nagabhatla, Saskia E. Werners, Sisir Bhandari, Sanae Okamoto and Serena Caucci

In 2021, the Rhine-Meuse region in European countries including Germany, Belgium, and the Netherlands was affected by devastating floods with > 240 causalities and damaged infrastructures worth billions of Euros. The event received global attention and various and diverse responses and reflections from researchers and research institutions, media, development organizations, public offices, and citizen groups, wherein the links to climate change were reflected as a common element of the discourse. The United Nations University Climate Resilience Initiative (UNU-CRI) has established a set of responses to this episode of regional/supranational/cross-border flooding events with the objective to address the growing risks of climate change, interconnected risks, and impacts, to assess the effectiveness of current adaptation strategies to extreme events, and to understand how to best ensure climate-resilient development looking beyond the conventional to 'building back better'. The initiative also focused on regional integration and cross-border collaboration along with other key dimensions that include innovative and transformative pathways for climate resilience (see the framework in Figure1). As the IPCC's alarming report (2021) stated, climate change is clear and present danger is inevitable and called for prompt action, The European flood of 2021 still left a lot to think about operational efficiency, 'gaps' and 'needs' in flood risk governance mechanisms/instruments. How do these processes operate beyond the state when impacts of such events spread beyond territorial borders? Can an enhanced understanding of the multilevel governance approaches help to scale best practices at regional and global levels and facilitate pathways towards climate resilience?

The project team conducted a set of interviews, analysis of media news, stakeholder mapping (Figure 2), and assessments of multistakeholder perspectives. The team further analysed multidimensional risk of climate change and disaster events, gaps, and needs in existing flood risk governance strategies and response-recovery measures in the affected states as well as the larger region sharing the water system. An open discourse was organized at the Flood Knowledge Summit (July 2022) to bring together the research community, practitioners, and experts from the local, subnational, and national government agencies and community representatives from the global north and south to facilitate a dialogue on learning about best practices towards boosting the efficiency of recovery pathways, to understand multi-sectoral recovery plans and protocols, diverse perspectives on risks, mental health impacts and psychosocial well-being of climate induced disasters, flood awareness/resilience at the local community level, and governance structures, including coordination mechanisms at different administrative levels. Other UNU agencies' initiatives are exploring the water-climate resilience nexus through programs and projects to support the resilience pathways, for example, the 'Regional Information on Climate Action" (RegIKlim) and the SMART-WaterDomain (UNU-FLORES) outlining context-specific adaptation measures and its implementation.

Images from the Multistakeholder dialogue at the Flood Knowledge Summit – inclusive and equitable approach to gathering perspective with particular focus on women and youth representation

Five Key points from the UNU Flood Knowledge Summit (2022)

1. Partnership and collaboration across sectors, agencies, communities, and other stakeholders to share knowledge and to co-create recovery pathways, driving collective action, and shifting the focus from passive coping to the proactive resilient building should be a key priority in resilience planning.

2. Understanding how uncertainties, deficiency in technical and human capacities, varying competencies, and systemic biases link to risk perception, response, and how that influences decision-makers and community outlook, and the importance of managing ambiguities should be key to resilience discourse.

3. Examining gaps in measures put in place for flood risk governance in a cross-border setting to understand how unpacking diversity in risk perceptions can potentially enhance or undermine the collective perception of the disaster like floods and what limits the uptake of innovation, approaches, tools, including capacity gaps and lack of community representation in existing risk governance and to support multisectoral and community-based approaches to reduce vulnerabilities is imperative.

4. In creating climate resilience pathways, more so as water-related extreme events are projected to intensify and will inevitably impact lives, livelihoods, and assets -better understanding of response and recovery mechanisms such as early warning systems, emergency preparedness plans, and response protocols, including mental health and psychosocial support, social protection, insurance support mechanism remain pertinent. Also, transitioning these processes from prolonged and uneven processes and creating a priority profile in disaster risk management planning, policy, and practice/ climate change adaptation is central to resilience building.

5. Capacity and awareness aspects are key to channeling impact and co-creation of transformative pathways, for example, the flood knowledge summit served as a platform for dialogue, exchange & learning about different actors (affected citizens; volunteers, local, regional and national authorities, and governments, scientists, and civil society) from the region i.e. experts from the European Union, and Global South to facilitate sharing experiences, dialogue, and learning, and collectively set an agenda for related networks and initiatives to transform into comprehensive research and policy (with focus on flood policy) agenda where people's voice and local community perspectives are integrated.

Conclusion

Climate Resilience Initiative is a call to action to ensure equitable resilience planning and to help states and

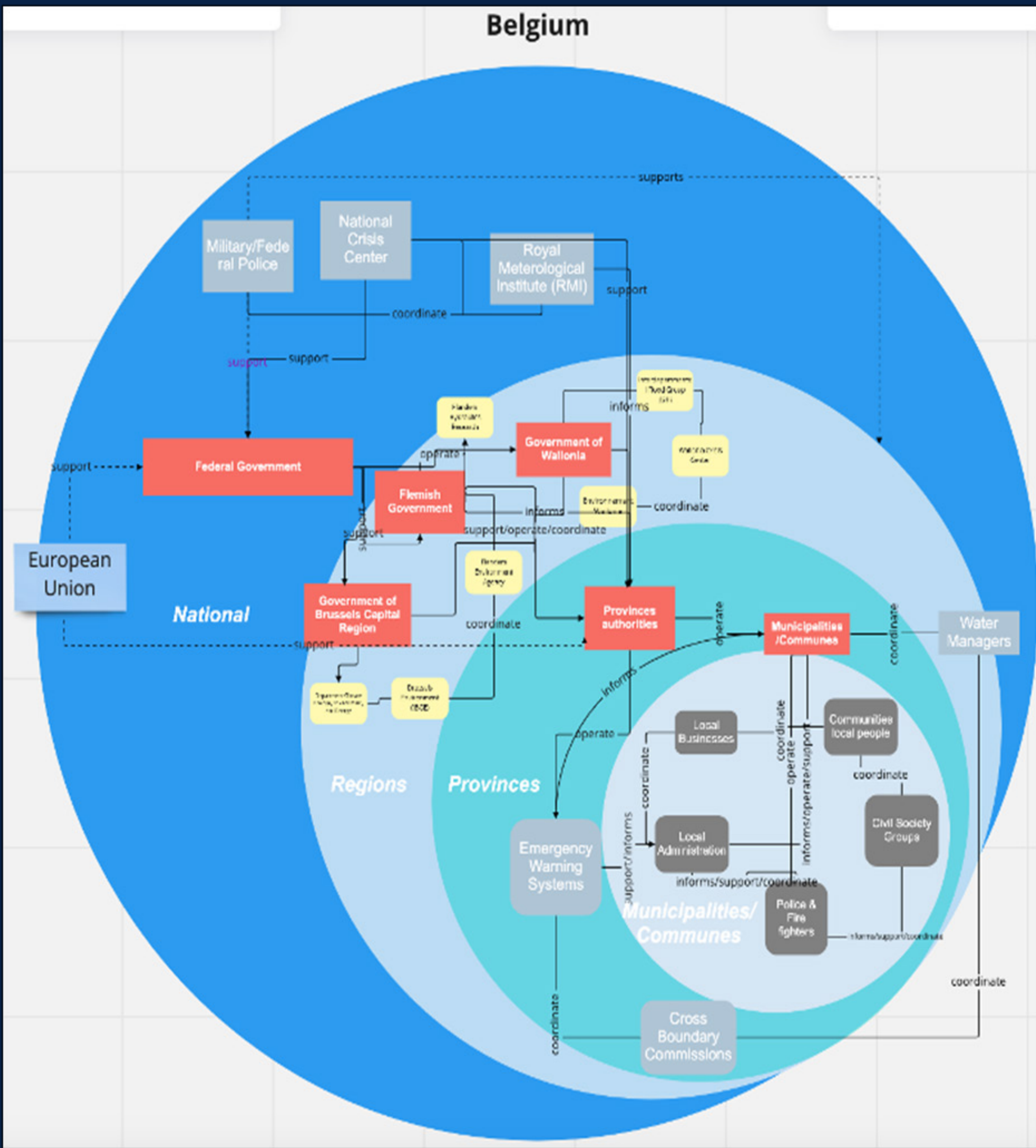
Figure 1: The structural framework (work packages approach) of the UNU Climate Resilience Initiative

communities, including different population groups (cultural cohorts, gender groups, geographical variability of impacted communities) create an inclusive and integrated resilience planning agenda by identifying gaps in climate services, competencies deficiency in recovery and response mechanisms, encourage the adaptation agenda to include a dedicated focus on psychosocial wellbeing, by addressing climate grief and generating public awareness. Additionally, collective and collaborative efforts and initiatives to share knowledge, shape policy, and drive action for facilitating pre-emptive adaptation strategies, and transformation to build climate resilience can help to achieve a 'climate secure future for all' and shift from 'fear to hope'.

Group Photo from the Multistakeholder dialogue at the Flood Knowledge Summit

Flooded banks of the Main river, Germany (iStock/ollo)

Figure 2 (below): To facilitate multilevel governance for disaster risk reduction and building climate resilience crucial dimension is an understanding of agents, agencies, and stakeholders interlinked governance and government nodes)- the stakeholder mapping was used as a tool to understand the need, at national, subnational and supranational levels. In this Figure, multiple levels of interlinked aspects in the context of flood/disaster risk governance in Belgium (Source: created by UNU, using multiple information sources)



4. Multi-Scalar and Cross-Sectoral, Hybrid Governance for Integrated Water Resources Management as a Pathway for Climate Change Adaptation:

Experiences From UNDP Supported Projects in Africa

Radhika Dave, Clotilde Goeman, Muyeye Chambwera, Madeleine Nyiratuza, Julien Simery

Introduction

One of the defining challenges of the 21st century is managing water resources in the context of climate change - enhancing access to it for daily life and societal needs while sustaining ecosystems and associated biodiversity integral to the maintenance of the water cycle. Integrated water resources management (IWRM), an important approach developed over the last thirty years to promote sustainable development, can enable effective climate change adaptation when climate risks are manifested through water. Both climate change adaptation and IWRM require coordination and collaborative management between institutions at the local, national and regional scales with appropriate governance frameworks and policies. In the absence of this vertical integration of policies and decision making, and inclusion of participatory processes and hybrid governance across scales, climate change adaptation through IWRM is likely to be ineffective or lead to maladaptation. This challenge is evident from literature. In this article, we examine how vertical integration and hybrid governance, as factors for effective adaptation and IWRM are put inpractice through a series of water management projects, supported by UNDP and funded by either the Green Climate Fund (GCF), the Adaptation Fund (AF) or the Global Environmental Facility (GEF), operational at different scales across Africa. We demonstrate the importance of enabling national policies, multi-scalar integration and hybrid governance modes through IWRM act to support adaptation to climate impacts.

Multi-stakeholder and multi-scalar governance and management: from policy to practice

In this section, we examine case studies where multi-scalar governance, coordination and planning are being supported to enhance vertical integration within the water sector in Comoros, Ghana, the Niger basin aquifer countries and the Cubango-Okavango River Basin countries. Each example illustrates different aspects of vertical integration and participation in water resource management with direct relevance to meeting the countries' climate adaptation needs (Figure. 1).

Comoros: Updating the national Water Code to allow for participative and cross-sectoral uses of water resources.

Comoros is a volcanic archipelago and small island developing state on the east coast of Africa, which has experienced floods, droughts and salinisation, which combined with a lack of appropriate water governance frameworks, are leading to limitations in water access and supply. To address these vulnerabilities, Comoros embarked on a lengthy revision of its 1994 national Water Code, with the revised code adopted in 2021 as the first step in the legislative process. Strongly embedded at the core of this revised Water Code are considerations related to IWRM, addressing climate change impacts, gender, and human rights. It paves the way for the establishment of a tariff system and payments for water services, essential to the sustainability of the water sector. The Code clarifies the roles and responsibilities of different actors at multiple levels and considers associated sub-sectors interlinked with the water sector, thus allowing for a more participative and decentralised mode of governing water resources and the development of a more resilient water sector on the three islands of the Comoros.

View from the picturesque beach in Moroni, Comoros (iStock/Antony Velikagathu)

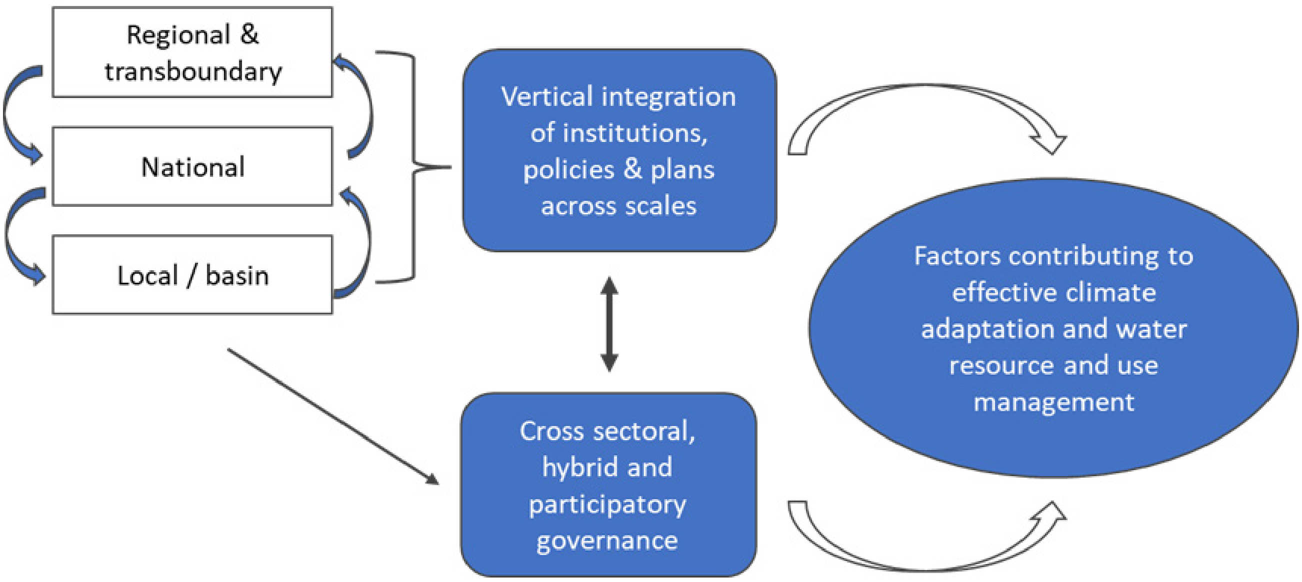


Figure 1: Conceptual framework for effective climate adaptation to manage water risks

Ghana: Strengthening water governance at the local to basin scale in Northern Ghana

Water availability is the single most important production and livelihood factor in the northern savannah regions of Ghana. There is an urgent need to address the negative impacts of climate change on water resources-reliant development and livelihoods. One of the challenges of managing water resources in the region is to account for and balance multiple and competing interests, uses and users. Thus, management decisions require participative planning at community, district and basin levels. Through an Adaptation Fund-financed project, the Ministry of Environment, Science, Technology and Innovation (MESTI) embarked on multi-level management planning and capacity building in Northern Ghana, with a focus on community level monitoring institutions, thereby strengthening water governance at the local level.

Wetlands near a village in northern Ghana (iStock/ Robert Ford)

Water management and investment plans for the White Volta, Black Volta and Oti river basins were developed, complemented by community water management plans. Regional, district and community-based adaptation monitoring committees were established and trained. These investments, together with functional community traditional by-laws and rules have been critical to avoiding conflicts, and for efficient and resilient water use and management in support of livelihoods solutions and are illustrative of adaptive management and hybrid governance necessary for adaptation.

Niger Basin and Iullemeden-Taoudeni-Tanezrouft Aquifer System (NB-ITTAS): Ecosystem based adaptation through cross-sectoral and multi stakeholder platforms

The NB-ITTAS is constituted of multiple interconnected transboundary ecosystems. The ecosystems of the Plateau of Mandara hill (Cameroon and Nigeria), the BSB Yamoussa complex (Cameroon and Chad) and the W park (Benin, Burkina Faso and Niger) are being supported by a UNDP-UNEP-GEF project, including the setting-up of coordination platforms. These platforms promote and implement ecosystem-based approach and the introduction of IWRM. Each platform has three levels of governance: regional, national and local, and coordinates with the Niger Basin Authority (NBA). These platforms recognize the transboundary nature of water and ecosystem management while providing a more localized and focused intervention than basin-wide mechanisms at the NB-ITTAS level. By being directly embedded under the NBA, the work conducted at the ecosystem-level can inform basin-level decision making. The localized actions also enable an enhanced understanding of local dynamics, with regards to the management of natural resources to avoid conflict over the resources. Indeed, the platforms are designed to involve stakeholders in every decision-making process, with the most localized decentralization. These cooperation mechanisms engage local communities, CSOs, NGOs, local and regional authorities directly in addition to national governments, demonstrating the adoption of a hybrid governance mode with diverse actors. This enables the adoption of a balanced system, where production, economic considerations, conservation and the maintenance of ecosystem services are all considered.

The Cubango-Okavango River Basin: Integrated management of a transboundary river basin

Communities living in the Cubango-Okavango River Basin are poorer than others in the riparian states of Angola, Botswana and Namibia. Political pressures to increase exploitation of water resources for local development resulted in competing water demands. Since 2001 the Okavango River Basin Commission (OKACOM) has been supported to improve the governance of Cubango-Okavango River Basin through the creation of regional technical committees to advise and coordinate on policy and socio-economic development, water resources management, biodiversity, and land use management. These committees led the Transboundary Diagnostic Analyses and formulation of a basin level Strategic Action Programme, within which a series of National Action Plans are nested. Member States established national Interministerial Committees that ensure harmonization of policies and coordinated actions in implementation of NAPs. At local level, through participative design approaches, community groups were supported to adopt regional and national level policy recommendations on integrated ecosystem restoration and livelihoods improvement through projects on climate smart agriculture, fisheries and eco-tourism.

Conclusion

The projects above put in practice vertical integration of policies and multi-scalar and hybrid modes of governance identified as critical for both successful IWRM and climate adaptation. The participation of different actors and government within a policy, governance and ecosystem management framework at the local to basin to regional level is enabling formal and informal institutions to enhance coordination and communication, allowing for improved participation in decisions and adoption. Updated and nested policies and institutional arrangements allow for cross sectoral and multilevel coordination, reduce redundancies, and enhance capacity to strengthen integration of climate change adaptation and IWRM. While the initiatives are ongoing, these cases illustrate a path forward to enable more effective adaptation and sustainable management of water resources.


Typical Okavango Delta Lands, Botswana (Getty Images/Pedro Ferreira do Amaral)

5. Paradigm Shift for Climate Resilient: Treating Water as a New Asset Class: Innovative Approach for Sanitation and Water Re-Use

Amgad Elmahdi, Lixiang Wang

Context

Climate change is evident around the globe, which requires bold actions now to achieve UN-SDGs and Paris Agreement. The projected impacts of climate change will reduce accessibility to water resources and escalate spatial and seasonal variations in water availability. Growing uncertainty and variability in climate, particularly precipitation, means increasing intensity and frequency of drought and flood, which in turn impact the water infrastructure/assets including wastewater and sanitation. The socioeconomic costs of floods and droughts – for which wastewater assets and storages are key mitigation and adaptation measures – are growing.

In addition, **water is one of the world's most essential commodities** and demand for water service has increased tremendously following the population growth, economic development and changing consuming patterns. Facing increasing demand for this scarce resource, **the global water business seems to offer investment opportunities**. Moreover, recent analysis provides a partial estimate of the scale of global economic losses related to water security: USD 260 billion per year from inadequate water supply and sanitation, USD 120 billion per year from urban property flood damages, and USD 94 billion per year to existing irrigators.

(Getty Images/Piyaset)

There is a building momentum to scale up global climate response. Translating this momentum into action requires significantly greater investments, **investments in a different set of inclusive assets** that address water security and provides sector-based or economy wide co-benefits to beneficiaries, e.g., job creation, health benefits, improved resilience.

Notably, climate finance is facing a dual challenge. It will have to both **reduce the present water infrastructure financing gap and ensure that this new infrastructure/asset is low-carbon, resilient to climate change, and meets the goals of the UNFCCC and Paris Agreement**. According to some estimate, the infrastructure gap worldwide could reach USD 3 to USD 15 trillion by 2040.Therefore, there is a **need for paradigm shift in the way how the water asset is defined, developed, and financed.** It is increasingly important to *treat water as a new asset class*, particularly as nations around the world (particularly developing countries) are set to experience *an anticipated 40% shortfall in water* by 2030 due to climate change, economic recovery and growth, population growth and resource competition. Investment in water could be one of the ways of tackling this deficit through **treating water as a new asset class**. As quoted by World Bank, "Water is the best investment the world can make to improve health, food security, gender equality, and the environment while transforming lives & communities.".

In the context of climate adaptation, **Green Climate Fund (GCF) is exploring non-conventional water sources** – including wastewater in general and water reuse and water recycling in particular including sanitation – as a new asset class. In some regions, reused water (untapped resources continue to increase as population increase) is already a water source (almost 80% of wastewater-untapped resources is untreated), however there are several barriers for broader adoption in many other countries including financial market barriers and assuring affordability and bankability of such projects.

Proposed Solution:

Maximize the investment value of existing and new assets: service providers can reduce overall investment needs and improve capital efficiency through operational improvement. Efficiency often results from better operational and maintenance with the objective to improve the service delivery to the user.

GCF's goal statement for water security is "GCF promotes a paradigm shift in water security that is low-carbon, resilient to climate change, and meets the goals of the UNFCCC and Paris Agreement". In simple means, this aims to create an enabling credit enhancement and blended financing environment through (i) provision of alternative funding solutions and (ii) the establishment of water reuse/sanitation infrastructure as a new water asset through defining its investment value and catalyzing private investment.

Definition:

The new asset class is "***an asset for adaptation and/or mitigation that is developed and funded using credit enhancement to crowd in private sector funding targeted towards developing debt capital market and acceptable financial returns but remain in line with ESG impacts and help to meet the targets set in the Paris Agreement and contribute to UN SDGs*** (Goal 6 –clean water and sanitation; Goal 3 – Affordable and clean Energy; Goal 13 climate action; Goal 14 – sustainable oceans and Goal 17– Partnerships with the involvement of the private sector) ***and providing water for domestic, municipal, and industrial purposes and allows municipalities to scale their water reuse and sanitation projects in partnership with private sector and/or governments purchase a service instead of an asset".***

Financial solutions:

One of the four pronged GCF delivery mechanism is mobilizing finance. To do that for the new asset, GCF's goal is **IF** finance is deployed to reduce risks and barriers of water security interventions, **THEN** financial resources will catalyze private and commercial finance at scale to support the paradigm shifting pathways of water conservation and preservation of water **BECAUSE** the financial viability of new asset classes in water security will be demonstrated. The **creation of a new asset class through** the development of a blended finance and an effective '*take-it-to-market*' approach would need to ensure:

- De-risking water security investments.
- Scaling-up blended finance into water security interventions; and
- Increasing collaboration with financial partners.
- Investors and private sector, are hindered from water projects for various reasons, including perceptions that
- Water is a public good and generally an under-valued resource;
- Water services are often under-priced, resulting in low cost-recovery for water investments;
- Water projects are capital intensive with high sunk costs and long pay-back periods;
- Difficult to monetise benefits and in turn reduces potential revenue flows;
- Water projects are context specific, raising transaction costs and making innovative financing models difficult to scale up; and
- Business models often fail to support O&M efficiency, hampering the ability to sustain service at least cost over time.

The proposed innovative financial model (Figure 1-next page) for the new asset class will address financial market barriers and ensure affordability and bankability to unlock water reuse investment, and how different financing options will overcome these barriers, including

• Reclassify and redistribute the responsibilities among the players across infrastructure design, procurement, construction (capital expenditure) and the long-term O&M of the asset.

• Access to **water is a human right**, however affordable tariff remains a challenge in revenue models, for which investors seek for full-cost recoverable tariffs.

• Constraints on commercial loan grace and maturation periods, which require such loans to be carefully structured to better suit investments in long-term infrastructure assets such as water reuse and sanitation projects.

• Public finance restrictions, particularly those which limit the extent to which municipalities can commit to long-term financing

New Asset Class-Characteristics

To ensure the delivery of the financial approach and creation of this new class, the following elements (shown in Figure2) are **essential in the design, development, and financing**:

- Financial
- SDGs
- Paris Agreement targets
- Acceptable revenue in line with SDGs, ESG impacts and Paris Agreement

Summary

Increasing the resilience of water sector to climate change requires paradigm shift in the way how water asset is defined, developed, and financed. The systemic change is only possible through (i) increasing focus on adaptation and treating water sanitation and reuse infrastructure as a new asset class; (ii) aligning new financial solution with Paris agreement targets and SDGs which is essential for recognition of wastewater and sanitation facilities as an asset class for private investment in developing countries; (iii) building capacities of project owners in structuring bankable and affordable projects; (iv) provision of innovative financing solutions including use of credit enhancement and blended finance mechanism that lowers the cost of borrowing and improve investment grade levels; and (v) creating partnerships and strengthen investor relationship among governments, financial institutions and wider stakeholder to improve investor's understanding and confidence.

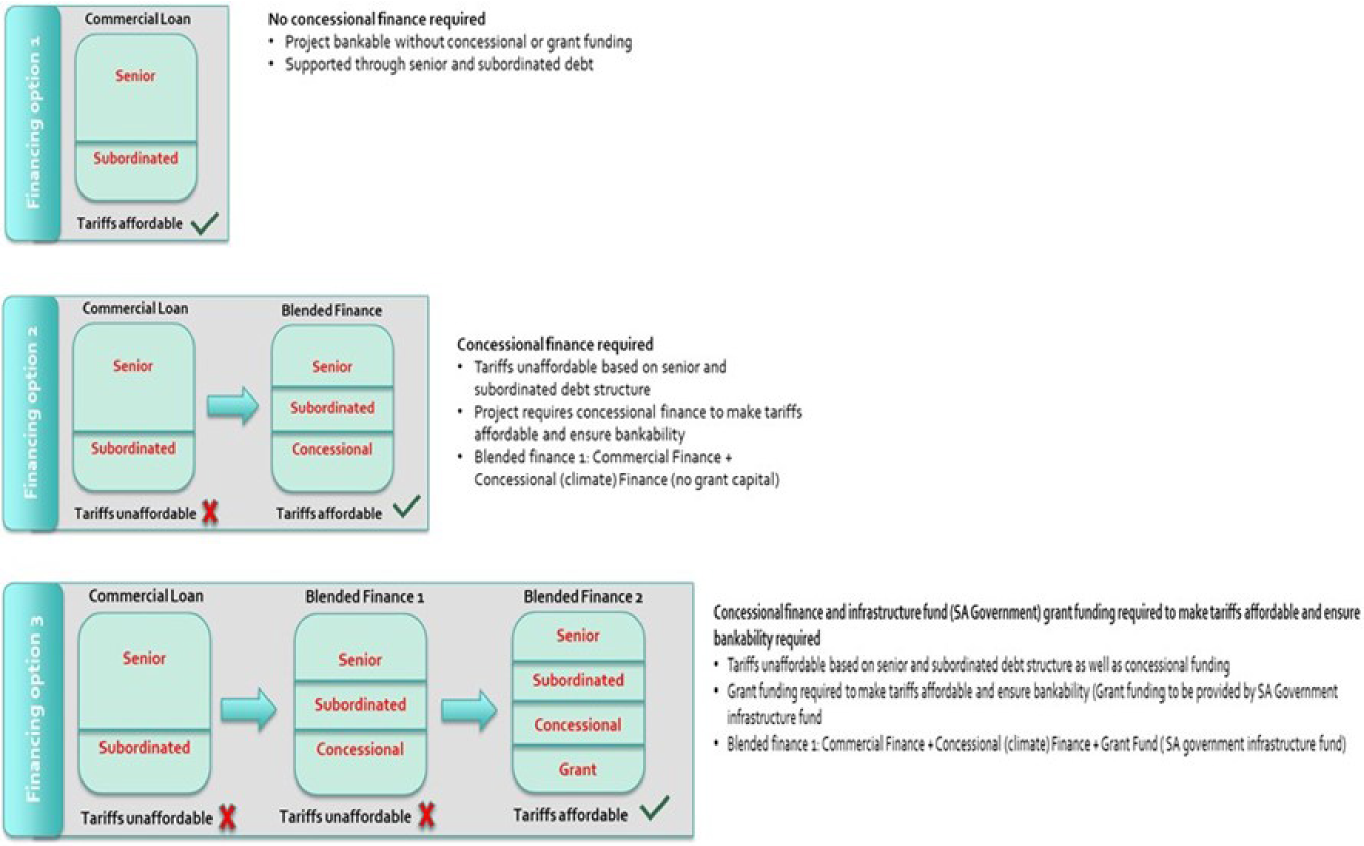


Figure 1. Financing options and affordability

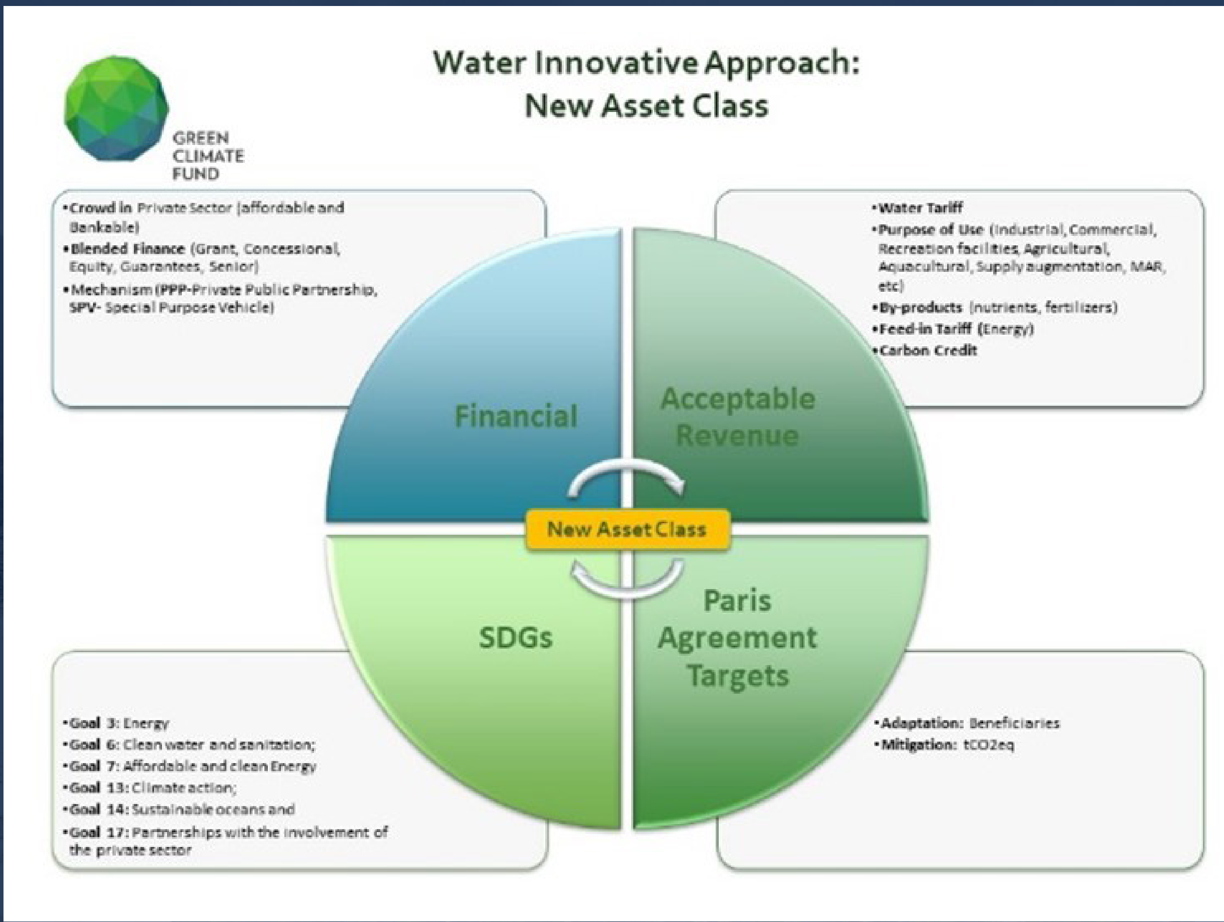


Figure 2. Key Characteristics of Water Innovation Approach: New Asset Class

6. Water Footprint Education To Build Water and Climate Resilient Communities

How Valuing Water Can Help Build Community Resilience

Kai Olson-Sawyer, Robin Madel

Introduction

For the past 10 years, "water" has ranked as a top risk in the World Economic Forum's Global Risks Report, and with good reason. As humanity's footprint expands, climate change is driving variability in precipitation patterns and the intensification of the water cycle. Under an onslaught of drought, water scarcity, flooding, fires and conflict, the world is grappling with the growing threat of water problems.

While trends and extreme events unfold in ways expected and otherwise, a multitude of experts have warned that building resilience is crucial. Significant infrastructure and policy adaptation is necessary to withstand water and climate risks, yet, knowledge and action are not identical.

Action to implement new infrastructure and policy depends on leaders gaining popular support among those they represent. Actions typically focus on increasing supply through dam construction, desalination, or moving water through canals and pipelines. Demand-side water management, however, is a frequently untapped resource that can balance supply needs.

A focus on demand-management might seem unusual in normal operational times, and leaders might not know how to begin. Educational programs are an effective place to start.

Education to Shift Demand-Side Behavior

The Water Footprint Calculator (WFC) project takes a novel educational approach towards water use that extends beyond typical conservation messaging. While the proj- ect is centered on the US, the approach could apply elsewhere.

Broadly, the water footprint concept aids communities in understanding the importance of water manage- ment and how people's actions connect water to larger systems, such as climate, food production, electricity generation, consumer goods manufacturing, etc. Additionally, because the water footprint concept is robust, it can be used to educate at multiple levels, for individuals, households, businesses, and nations. The concept makes abstract water use and quantification more concrete. Real-life problems like climate-induced drought and its impacts, and solutions like water-saving tips, are presented to impart a sense of hope and control over people's lives.

The project's commitment to water use education over the past 14 years has developed into a public-facing, demand-side water and climate-resilience educational platform geared towards teachers and students. The WFC educational content is geared toward formal and non- formal educators alike, ranging from kindergarten to undergraduate. The project goes beyond the water cycle or localized water- shed concerns—a common US approach.

The project is also distinguished from a crisis-based approach of conservation during acute events where warnings of imminent shortages are issued. While necessary, such approaches typically address near-term stressors.

Instead, the WFC approach continually educates people about their water use and how it affects their surroundings—from local to global. This fosters resilience and prepares communities for impending water-related problems, such as potential scarcity or conflict over water. It also provides tools and strategies to adapt and reduce demand now to make a lighter lift later.

WFC engagement intends to "meet people where they are" or, in other words, raise awareness and increase information access for students and the public. To this end, the project has concentrated on making its content free, informative, interactive, and appealing, with special emphasis on creating web apps like the Water Footprint Calculator, Food Guide and Food Quiz.

Since most of the world's population has access to smartphones and other digital devices, people – especially youth – can see, read and explore the content. Thus, a digital strategy can lower the barrier to entry. Further, resources like lesson plans and issue pages are available for educators, students and outside individuals alike to gain greater comprehension on the science and context of water use, management and impacts.

Potential Educational Efforts

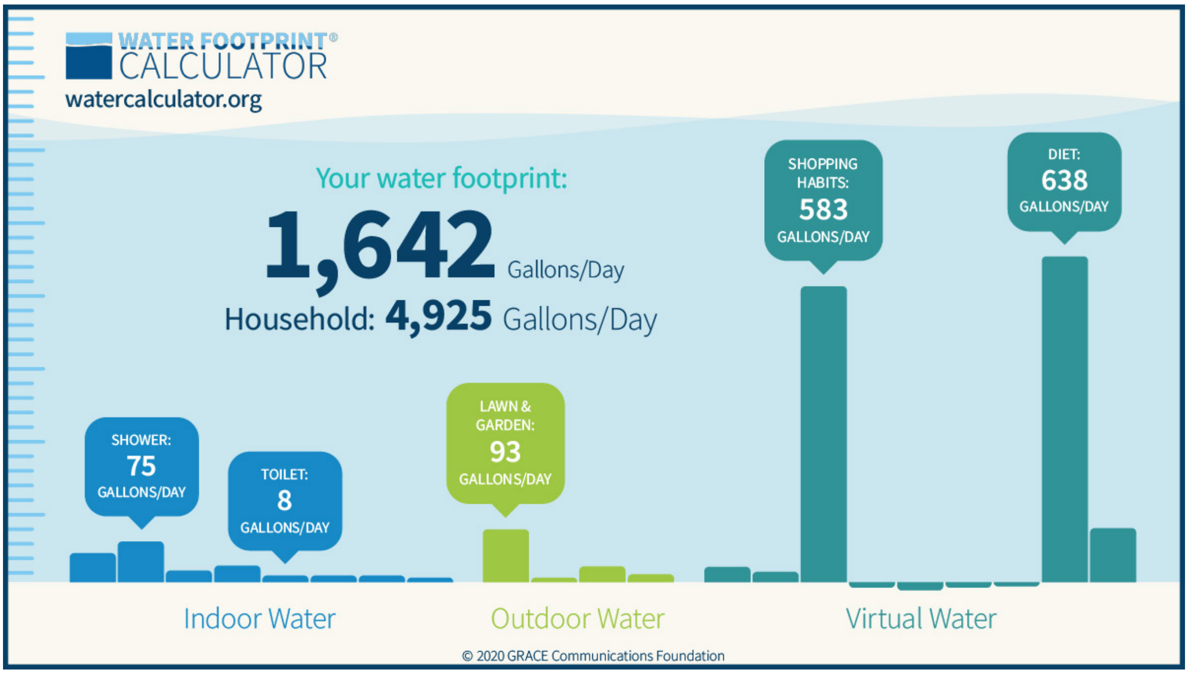


Figure 1. Typical Results from the Water Footprint Calculator

The water footprint concept lends itself to further development of educational resources and campaigns that address water-climate issues specific to a community, watershed or region.

For example, the Inskeep and Attari study, "The Water Short List," presents a catalog of actions and activities that effectively reduce direct water use in the household, such as fewer toilet flushes, modified lawn watering, etc. Expanding the list to incorporate virtual water conservation recommendations couples direct and virtual water use knowledge with behaviors that promote sustainable water use, and personal and community water footprint reductions could be more easily achieved.

Actions like food waste reduction, meat and processed food cutbacks, electricity, and fossil fuel conservation could magnify the water, energy, and material savings through cumulative action that extends beyond typical water conservation approaches. As Ruiz et al. note, pro- grams that focus on residential and smaller water us- ers do not meet the demand challenge because they're "not the dominant driver of water stress, and available household savings measures are not sufficient to transi- tion the majority of [US] counties out of water stress during a drought." With pre-existing programs, cam- paigns could spur users towards educational resources and tools that target systemic water savings, for example, a program that highlights that "wasting food is wasting water" or "wasting energy is wasting water."

Moreover, a systems-based approach could be tailored to address the water-use behavior changes unique to a specific region, climate, watershed or industrial mix. For instance, in California, where water and energy are closely connected – about 12% of the state's energy supply is used to treat and move water – a concerted "Save Energy, Save Water" campaign could be effective. In this way, the co-benefits of water conservation and climate action can be achieved simultaneously.

Comprehensive Education Builds Resilience

The Colorado River basin offers a cautionary tale. A recent LA Times article detailed how, for decades, scientists have forewarned Colorado River water managers that aridification and overall lower water flows in the basin were imminent.

If public officials, water managers, irrigators and others worked to reduce water footprints 30 years ago, leaders might not be scrambling to manage water for the 40 million people, economies and ecosystems that rely on a shrinking supply. A comprehensive educational approach is necessary now, one that focuses on impacts that stretch beyond turning off the tap. The data and information already exist, and governments, universities, civil society, the media, and educators can take advantage of those resources to lead their communities toward a more resilient, changing world.

Figure 2. Water Footprints of Select Agricultural Products
from the Colorado River Basin (US averages)

Water Footprints of Select Agricultural Products from the Colorado River Basin (US averages)

Agricultural Product	Liters/Kilogram	Gallons/Pound
Beef	14191	1704
Cotton (finished textile)	8099	973
Cheese (from cow's milk)	3945	474
Soy beans	1662	200
Sorghum	1248	150
Avocados	1209	145
Corn (maize)	761	91
Grapes (table grapes)	417	50
Oranges	331	40
Carrots	124	15
Lettuce	113	14

Data taken and converted from: Mekonnen and Hoekstra, A.Y. (2010) The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products, Value of Water Research Report Series No. 47. UNESCO-IHE. Volume 2: Appendices; and Mekonnen and Hoekstra, A.Y. (2010) The Green, Blue and Grey Water Footprint of Farm Animals and Animal Products, Value of Water Research Report Series No. 48. UNESCO-IHE. Appendices Volume 2.

7. Water Provision and Climate Change Mitigation: Implementation of Ocean Thermal Energy Water Resources in The Bahamas

John Bowleg, Kristen Welsh

Abstract:

Sustainable development in small island nations is typically constrained by water supply and energy demand. To address these challenges, The Bahamas is currently developing Ocean Thermal Energy Conversion (OTEC) strategies to harness the inverted geothermal conditions of the groundwater throughout the islands. Through the implementation of OTEC, the country will enhance its ability to provide potable water, in addition to adopting a renewable source of energy that will better withstand climate change-induced shocks. The Bahamas is exploring advanced studies and research opportunities through a strategic Atlantic-Pacific Alliance with universities in Japan.

Background

Sustainable development in The Bahamas is challenged by water and energy supply, as is typical of small island nations. Freshwater is lacking throughout the archipelago, and often large-scale interventions are necessary to provide adequate water to residents. Additionally, The Bahamas is heavily reliant on fossil fuels for energy with the country only sourcing 1% of its energy from renewables in 2020, despite a National Target of 55% renewables by 2030. In recent years, Ocean Thermal Energy Conversion (OTEC) has been promoted as a mechanism to harness energy from ocean water to provide renewable energy while concurrently providing potable water OTEC harnesses the energy from ocean water through temperature differentials between warm and cold water.

Project Site

The geology of The Bahamas is characterized by continuous carbonate/evaporate rocks that extend to a depth of 6,096 meter (20,000 feet). This substrate is extremely porous to the surrounding ocean water, which results in ocean water penetrating the subsurface below the islands. Under typical conditions, such as in larger continental areas, groundwater tends to increase with depth. However, due to the high connectivity of groundwaters in The Bahamas to the ocean water, colder water penetrates the subsurface and the temperature of groundwater decreases in what is known as a reverse geothermal gradient.

The Bahamas is currently promoting the use of OTEC to capitalize on the reverse geothermic gradient that exists naturally throughout the archipelago. As the reverse geothermal gradient has been observed down to depths of 304.8-meter (1,000-ft) with a temperature of 20.3°C (68.5°F) (Ardaman & Associates 2013), additional boreholes will be excavated to observe the temperatures to an even greater depth. Geophysical logs and pumping tests have also confirmed that the subsurface is highly permeable, allowing for high quantity extractions from the groundwater table and depositions of return water into the groundwater table.

Available data reveals that subsurface water exhibits the same general temperature as seawater of the same depth, and therefore the data suggest that this subsurface temperature trend extends to even greater depths. It is anticipated that a depth of 914.4 m (3000 ft.) would provide the temperature necessary, 7°C (45°F), to preliminarily apply OTEC technology throughout The Bahamas.

To date, the provision of freshwater supply has been heavily sustained by desalinization, specifically seawater reverse osmosis (SWRO). The SWRO process uses groundwater supply and discharge wells. The temperature profiles of the existing SWRO supply wells reveal a range of 24°C to 25°C (75°F to 78°F).

Proposed Project

By the integration of OTEC with the SWRO technologies, it is anticipated to possibly attend to key climate resilience goals of The Bahamas: Sustainable Development Goal (SDG) #6 - Clean Water & Sanitation, along with SDG#7 - Affordable & Clean Energy [Renewable Energy Systems]. A minimum OTEC temperature differential of 20°C (36°F) is required between the hot and cold source; the average surface source water from shallow wells is 27°C (81°F), and the optimum OTEC cold-water source would be 7°C (45°F). The OTEC minimum required hot source, per existing readily available cold, is 45°C (113°F). Hydraulic conductivities at depth further support this hydrological effort.

An OTEC Pilot Project has been proposed for commencement with desired flows of 54,510-m3/day (10,000 GPM) at 24°C to 25°C (75°F to 78°F) from two to three boreholes with an adjustment of the high temperature source water for the OTEC, using Solar Photovoltaic Cells to raise the hot source temperature to 50°C (122°F). A small capacity turbine (OTEC Generator) will initially run the distribution and/or high-pressure pumps of the SWRO facility.

A projected 914.4 m (3,000 ft.) test well has been proposed for the full potential of the OTEC Technology in The Bahamas. At a depth of 914.4 m (3,000 ft.), the cold seawater supply source is anticipated to be 7°C(45°F).

This project will enhance sustainable development of The Bahamas by developing technology to promote renewable energy sources and potable water supply, interlinking water and climate. OTEC is a promising option for the country, and other small islands have the potential to benefit from using this technology to reduce the environmental impact of providing fresh water and energy.

Sample Depth (ft bls) | (m bls)	Typical Vertical Hydraulic Conductivity (cm/sec)	Typical Vertical Hydraulic Conductivity (ft/day)	Porosity (%)
80 | 24.4	2.0E-06	5.7E-03	12.1
200 | 61.0	1.4E-05	4.0E-02	9.2
500 | 152.4	2.8E-05	7.9E-02	6.7
550 | 167.6	1.4E-08	4.9E-05	6.3
600 | 182.9	2.4E-04	6.8E-01	7.9

Note: bls = below land surface

Figure 1. Typical Hydraulic Conductivity Readings for The Bahamas

Figure 2. Physical Map of The Bahamas

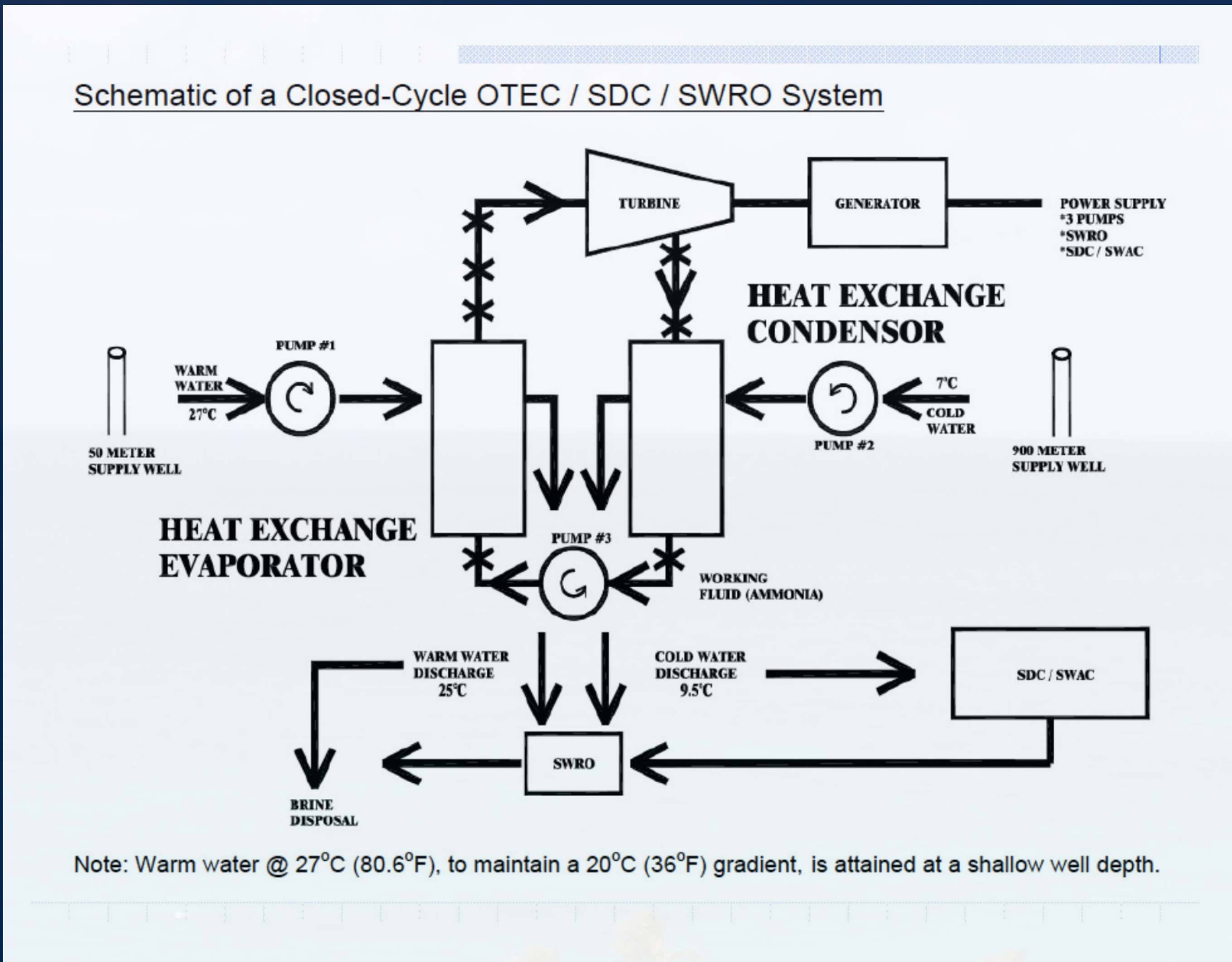
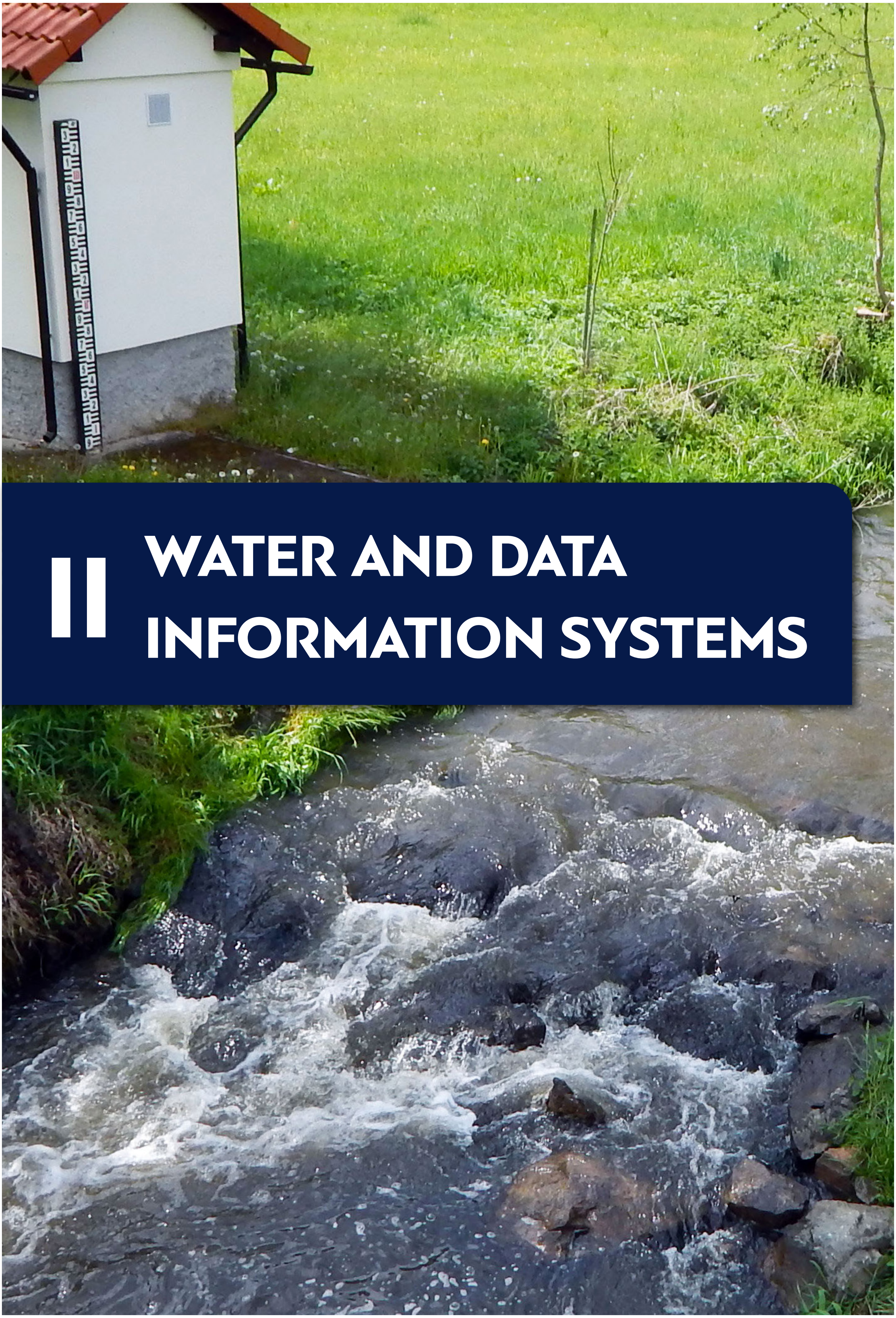


Figure 3. OTEC-SWRO Figure

II WATER AND DATA INFORMATION SYSTEMS



1. An Integrated Drought Management Tool Application for Maipo Basin, Chile

Benjamin Lord, Juliana Corrales, Fekadu Moreda, Raul Muñoz

Introduction

Droughts are naturally occurring phenomenon generally characterized by prolonged periods of low rainfall. Although no single definition is available for droughts, a helpful lens is to categorize droughts by impact and duration. Drought characterization varies widely by location, depending on local climate and the monthly distribution of rainfall. For example, temperate climates with even yearly rainfall may experience drought if rainfall is low over 2-3 months. Mediterranean climates, which are highly seasonal, may typically experience four or more months of no rainfall. No single definition can characterize drought in both watersheds without considering local climate history.

Drought indices can combine multiple factors such as precipitation, streamflow, and soil moisture to quantify severity in a local context using historical data. Numerous indices exist, varying greatly in data needs, complexity, and suitability for specific applications. The World Meteorological Organization (WMO) Handbook of Drought Indicators and Indices catalogues many of the most popular and scientifically-accepted approaches to quantifying drought.

While drought indices can be theoretically simple to calculate, the practicalities of processing large amounts of data and automating visualization over large areas can be cumbersome for decision-makers. To address this issue, we have developed a Drought Management Tool (DMT) inside the GIS-based WaterALLOC water resources planning platform.

Modelling Tools

WaterALLOC is a GIS-based model platform that combines the HydroBID hydrologic modelling system for Latin America with MODSIM, a network model used to simulate withdrawals, reservoirs, and other human effects on the watershed. The HydroBID modelling system comprises a semi-distributed hydrologic model indexed to a geo-referenced database of catchment boundaries and stream segments for the entire Latin America and the Caribbean (LAC) region. This database, known as the Analytical Hydrographic Dataset (AHD), contains over 230,000 catchments with an average size of 83 km2 for South America and 23 km2 for Central America and the Caribbean. AHD contains remotely sensed information associated with each catchment, including drainage area, stream length, slope, land uses, and soil types in a database. HydroBID applies these parameters through an enhanced version of the rainfall-runoff Generalized Watershed Loading Function (GWLF) model, coupled with a novel lag-routing methodology developed by RTI to estimate streamflow within each catchment composing a watershed.

MODSIM, developed by Colorado State University, is a decision-making support system that uses optimization in a stream network to help watershed managers analyze water supply in the face of hydrological uncertainty and demand growth.

WaterALLOC streamlines the data processing between HydroBID and MODSIM, offering a solution to perform water availability analysis, including river and reservoir operations with the simulation of water permits and priorities, using all the river operations tools and customization provided by MODSIM. In addition, WaterALLOC enhances the user experience for both HydroBID and MODSIM users, allowing the HydroBID user to use the GIS interface to run the system and adding easy-to-use input dialogs for agricultural and municipal demands for MODSIM.

Modelling Drought Management

The new DMT in WaterALLOC supports rapid calculation, visualization, and analysis of drought index values with data imported from existing HydroBID models. Currently, the Standardized Precipitation Index (SPI) is the only index supported by the module, with more complex drought indices to be added in future versions. SPI was selected for the initial index because it is widely accepted and recommended by the WMO, and the calculation only requires precipitation data. Droughts can be evaluated at multiple time scales depending on the impacts. To support this, index values are calculated for two time periods, near-term and long-term, which users must define (Figure 1) (see Handbook of Drought Indicators and Indices for guidance). Once calculated, drought index values can be visualized for any time step of the simulation (Figure 2). In addition, users can develop animations to visualize how droughts evolve spatially and temporally. These maps are designed to be readily sharable with audiences regardless of technical knowledge.

Case Study: Maipo Basin, Chile

We applied the DMT in WaterALLOC to a previously developed model for the Maipo watershed, a semi-arid basin in Central Chile. Streamflow is snowmelt-driven; hence high streamflow values occur during the summer months (September–March) and very pronounced reductions in winter (June-September). This strong seasonality makes the basin vulnerable to the impacts of droughts. To quantify drought in the Maipo basin, we utilized the DMT developed in WaterALLOC to calculate SPI for all catchments in the watershed (Figure 2). Based on the guidance of the SPI User Guide, SPI was calculated at two-time scales: 6-month (short-term) and 12-month (long-term). The short-term duration of 6 months allows planners to visualize near-term precipitation deficits. This is particularly useful for monitoring drought conditions in the watershed during the rainy winter months. The long-term duration of 12 months captures the total rainfall of the past calendar year, which will also include the previous year's rainy season. In a watershed with highly seasonal rainfall, such as Maipo, the long-term SPI can implicitly capture the effects of snowpack and soil moisture in the headwaters. These SPI values were used to develop quantitative thresholds for triggering water demand restrictions under a Drought Management Plan.

Conclusion

Timely and reliable drought detection is the basis for sustainable drought management. We developed a set of drought management tools within the WaterALLOC modelling system for water resources. Users can now evaluate droughts according to their unique local context. In addition, rapid mapping tools allow visualization of how droughts evolve over time and across space. We applied these tools for a case study in the Maipo basin of Chile, which guided the development of a demand management strategy in which demands were reduced dynamically in response to drought levels. WaterALLOC allows planners to gain insight quickly and plan drought mitigation strategies by quantifying each step of the drought management process.

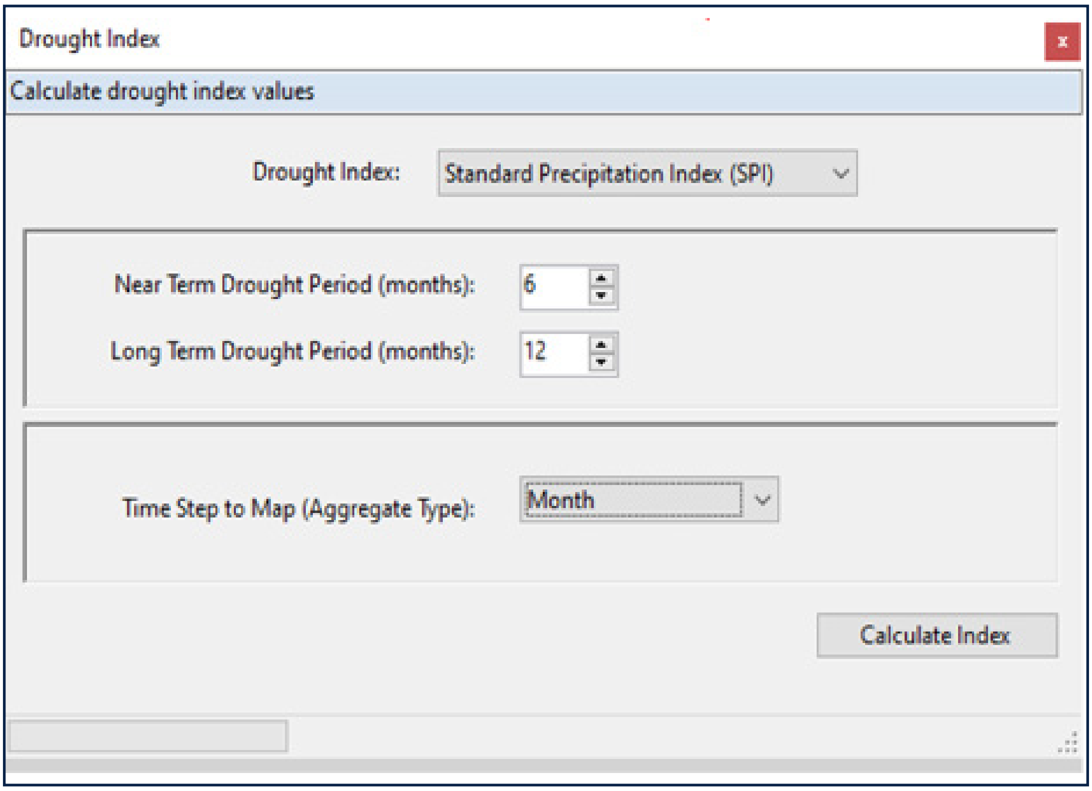


Figure 1. Drought Index calculation setup form in WaterALLOC

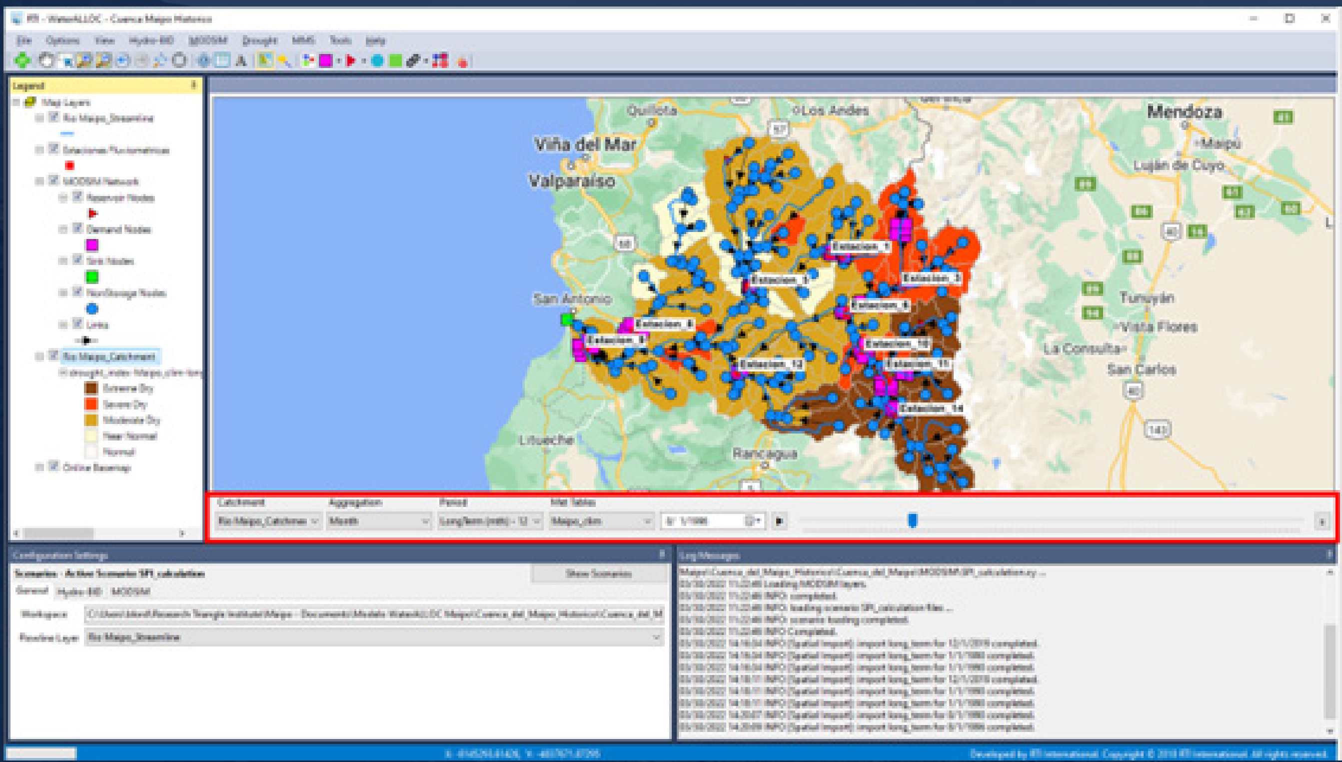


Figure 2. WaterALLOC interface showing 12-month SPI by catchment in the Maipo watershed on August 1, 1996. Darker colours indicate more severe drought conditions.

2. Towards Making Hydrological Status Assessments and Outlook Products Comparable, Compatible, and Accessible: WMO HydroSOS Initiative and Beyond

Sulagna Mishra, Luis Roberto Silva Vara, Adriana Calderon, Michael Schwab, Stefan Uhlenbrook

Introduction

The Rationale

"We cannot continue to take water for granted and expect to achieve the Sustainable Development Goals." – Antonio Guterres, Secretary-General United Nations, 22nd March, 2018

Water stress, water-related hazards, and water quality pose increasing challenges to society and the environment. Around the world, more than 2 billion people live in countries experiencing high water stress, and the impacts of floods and droughts are worsening (WMO, 2021). Worldwide, these events affect millions of people, and damages are estimated to cost billions of US dollars annually (UN WWDR, 2020). Scientists expect water-associated risks to intensify in the coming years due to climate change, changing water availability including from the cryosphere, population growth, food production and consumption, and increasing economic activities. Managing water for people and the planet is a challenge that decision-makers can only meet if they have reliable, relevant, and timely information to make informed decisions. Yet, according to the WMO Global Hydrological Survey (HydroSurvey) conducted in 2020 (WMO Hydrohub), only 84% (from 75 countries who filled the survey) collect discharge information. It was also clear from the HydroSurvey that the capacity to monitor and manage water resources is fragmented and inadequate globally which inhibits informed planning and decision making.

Problem statement:

Effective water management and climate change mitigation and adaptation require water information to address questions such as: How much water is available now and in the future? How can societies be protected and prepared for water-related disasters like floods and droughts? How much carbon uptake can we promote through better water and land management? In order to answer such crucial questions, we need knowledge about water resources' status and outlook.

Currently, water information is fragmented, has significant gaps, and is partially inaccessible. As a result, water management and planning are not always informed by scientific knowledge and are often not fit for purpose. The growing information gap hinders countries from further optimizing the use of water resources for societal benefit, adaptation to climate change, informed action, and ecological sustainability.

Therefore, there is a need to:

1. Set up a global operational mechanism for integrating hydrological status assessments and outlooks from and for national and regional stakeholders. The HydroSOS framework (WMO, 2021) aims to ensure the provision of assessments of water resources and hydrological forecasts in a consistent and comparable way on a local, regional and global scale to support the sustainable development agenda with baseline data on water.

2. Assess and summarize the status of the water resources at the global scale at the regular time interval. Producing such summaries year after year will help identify the effects of climate change and possibly other societal changes in different parts of the world, locate hot spots, and help governments, policymakers, and water managers make informed decisions regarding resource conservation and allocation.

3. Establish a data portal that combines water-related information curated by different organizations in one platform. This portal should ensure transparent and easy accessibility of water data for all stakeholders and users, further improving forecasting capabilities, water management, climate smart development planning and policy-making.

The Framework - HydroSOS and Beyond:

WMO and its partners aim to provide solutions to the above three needs, empower national and international water management, and catalyse bilateral and multilateral cooperation through trustful water assessments and outlooks. The objective is to foster an interconnected global system that helps countries and future generations understand how global hydrological systems change with a changing climate and human management of water systems and land surfaces. The framework consists of the three following components:

Component 1: WMO Hydrological Status and Outlook System (HydroSOS)

The hydrological Status and Outlook System (HydroSOS) (WMO, 2021) aims to close the gap in capacity and hydrological information, acting as a system ensuring that countries can assess and provide a comprehensive overview of the current status of their water resources at different temporal and spatial scales. HydroSOS framework aims at organizing the provision of seasonal and sub-seasonal hydrological forecasts in a way that is consistent and comparable on a global scale. This includes surface and groundwater hydrological systems, soil moisture, cryosphere, water quality, and predicting how they will change in the next months. HydroSOS supports National Meteorological and Hydrological Services (NHMS) to use locally produced data for hydrological analysis, complemented with remotely sensed data and information from downscaling global climate and hydrological models.

HydroSOS is the first global operational mechanism for integrating hydrological status assessments and outlooks from and for NMHSs, collaborating with transboundary basin organizations, global modelling centres, and technical and implementing partners.

Once operational, it will aid the decision-making process of Members (WMO Member countries) by enabling the provision of the following:

1. An overview of the current hydrological status at various spatial scales (global, regional, national, local)

2. An appraisal of where the current status is significantly different from "normal", and

3. An assessment of whether this will likely improve or worsen in the next months.

These products will inform water resource management from available, systematically collected, comparable and trustworthy information validated on the local scale, consistent with national, regional, and global information. Moreover, the products will constitute vital, actionable water resource information to stakeholders in sectors such as agricultural production, energy generation, disaster risk reduction, and water supply.

HydroSOS provides a framework for countries to develop hydrological status assessments, outlooks, and a platform to access these national and transboundary basin products. Moreover, it will help integrate them into regional and global scales for use in the global community. In this way, HydroSOS fills information and capacity gaps with tailored products, required inputs for the provision of hydrological services, and makes much-needed information available to NMHSs end-users and customers.

Structure

HydroSOS is based on three pillars to reflect the value chain from measurement to service delivery (Figure. 1 shows example activities under the technical and implementation components).

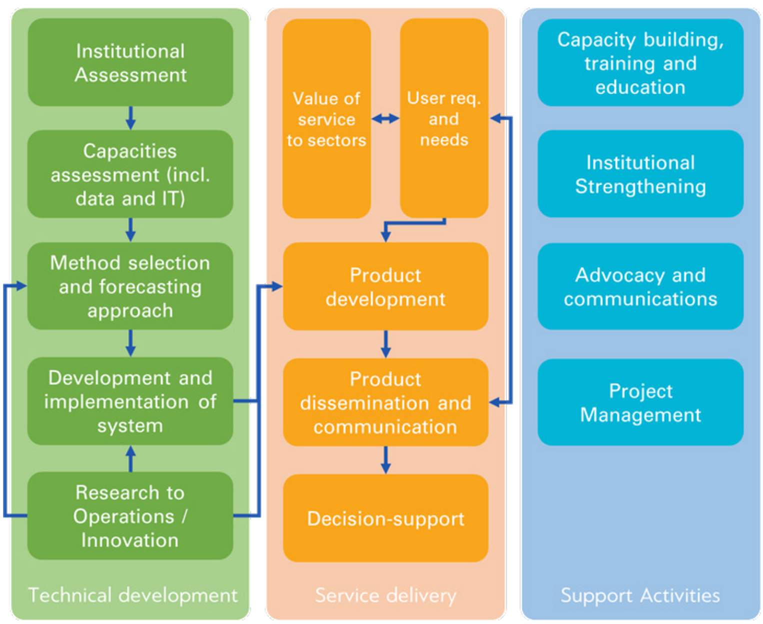


Figure 1. Activites for setting-up a Hydrological Prediction System (WMO, 2021)

1. Technical development: Design and testing of data, methods and tools for a hydrological status and outlook system

2. Implementation: Implementation of the hydrological status and outlook system and delivery of tailored services to end-users and customers at global, regional and transboundary/national/local scales

3. Coordination and support: programme management and support activities for strengthening institutional frameworks, capacity development, and ensuring sustainability.

Current Status:

HydroSOS ran a pilot phase from 2017 to 2021 where several developments like designing a demonstration portal, defining the minimum viable products, assessments of the current capacities of the hydro-meteorological capabilities and gaps at national and basin scale were conducted (WMO, 2021). Since the end of 2021, HydroSOS has entered the implementation phase, where proposals for its deployment are currently under development across scales in several countries and regions.

Component 2: Annual Global State of the Water Report

Globally, 1 cm of fresh water equivalent, i.e. 10 liters per square meter, has been moved annually from the the land (to the ocean) in the past two decades (Figure 2). At the same time, a large proportion of the world's population faces significant water stress (Figure 3). Therefore, there is a need to understand the current availability with respect to historical normal at a global scale to plan for and adapt to future climatic conditions and development ambitions, and to implement the most effective climate mitigation strategies.

An annual state of the world's water report will help us quantify the effect of climate change and other environmental and societal processes on water resource changes. When produced at regular intervals, this annu-

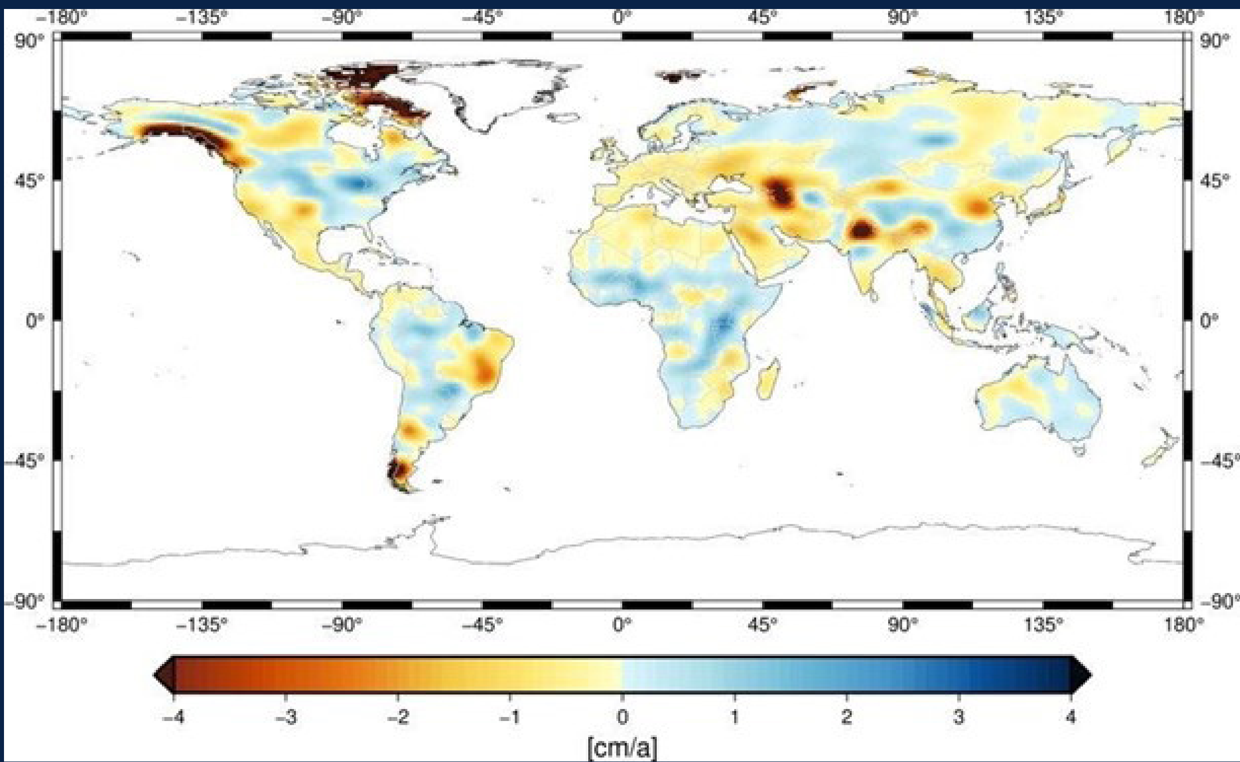


Figure 2: Map depicting total reduction in terrestrial water storage per year in last 20 years globally. Source: GFZ Potsdam, Germany

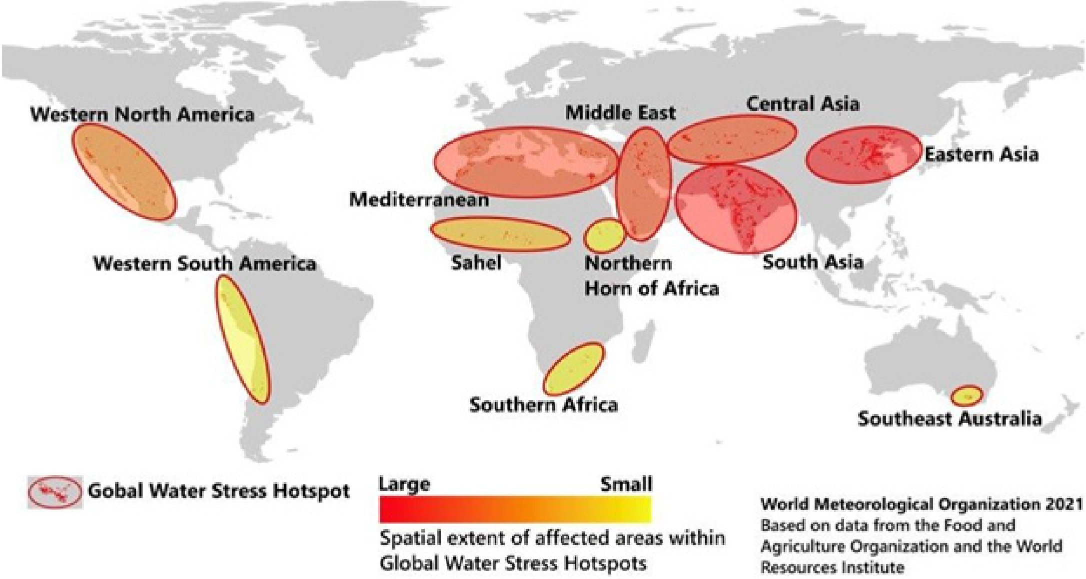


Figure 3: Global water stress hotspots. Source: WMO State of Climate Services: Water (2021)

al summary will help monitor, compare and understand the changes and thus support high-level decision-making and policy-making processes.

The Global State of the Water Report will present an overall picture of the available water resources in different basins globally during the previous year, the first pilot version for 2021 is currently in press. The annual report allows for the assessment of water resources and threats with respect to mean conditions and provides insight into the change in current conditions compared to historical water data. Complementing the annual State of the Climate Report issued by WMO, the water report will allow assessing the impact of activities targeted at integrated water and climate action at the global level.

Current Status:

In November 2022, WMO will launch the first Annual State of the Water Report providing an appraisal of the stream flow, terrestrial water storage, major hydrological events, and the importance of the cryosphere for the calendar year 2021. Once HydroSOS is operational, the Annual State of the Water Report will be derived from the HydroSOS portal.

Component 3: Global Water Data Portal

Water data and information is currently scattered over different portals and platforms on the international, regional and national level. Having a centralized portal providing access to geospatially referenced information allows using data from different sources and helps in data visualization (and derivation of indicators) and communication. Access to water data and information will support improved policy development, national and regional adaptation action, and water monitoring and management efficiency.

The Global Water Data Portal is an essential component of the Water and Climate Coalition (WCC) action plan and the Water and Climate Leader's call for action (WCC,2022) The portal will have close linkages to existing Water Information systems like AQUASTAT, FAO's Global Information System on Water and Agriculture, and WMO and WCC activities like the HydroSOS. The HydroSOS products as well as relevant products from other organizations will feed into a Global Data Portal make as much as possible information accessible to all users.

The Outcomes of the Introduced Framework

The framework discussed in this article supports the global agendas – 2030 Agenda for Sustainable Development, Sendai's Framework for Disaster Risk Reduction and the Paris Climate Agreement, and it fosters international and regional cooperation among countries. If fully implemented, major benefits include:

- Availability of a comprehensive overview of the hydrological status at global, regional, national and basin scale. and further outlook to the available resources at various spatial and temporal scales.
- Enhanced local, national and regional operational capabilities support water resources and land management.
- Shared information products inform decision-makers and policy-makers and prevent conflicts at a river basin scale.
- An integrated regional/global overview of the resources and their outlook and trends will assist the aid and development sector, NGOs (non-governmental Organizations), and UN (United Nations) agencies in anticipating action and response.

- The information derived from products enabled by HydroSOS will inform the different sectoral water users, including energy, public water supply, agriculture, disaster risk reduction, and the environment.
- The global water data portal ensures easy discovery and access to water-related information at one and several locations, making it convenient for stakeholders, policy-makers, and governments to look at and compare multiple variables and parameters. It also ensures that information generated by organizations with limited capacity to host and maintain geospatially referenced portals for water information get assistance and support to share and access data.

3. Spatio-Temporal Analysis of Extreme Rainfall Events Across the South-East Region of Cote d'Ivoire

Trends of Precipitation Extremes by the Method of Climatic Indices in the District of Abidjan Over the Period 1981–2020

Koffi N'zuako Franck, N'guessan Bi Vami Hermann, Kan Jean Kouame, Badara Alioune Kone, Badara Alioune Kone, Allechy Fabrice Blanchard, Jean Patrice Jourda.

Introduction

With climate change, extreme events such as heat waves, droughts or floods can cause many challenges for the most vulnerable communities (coastal countries, island states). Extreme weather events are expected to become more frequent as the climate warms. The fact is that climate change is already underway, and this can create serious environmental problems with irrefutable consequences for humans. Like the metropolises of the sub-region, Abidjan and its municipalities suffer from bad weather. And with growing populations and changing weather patterns, flooding has become more frequent in recent decades. They cause a lot of material damage (farming, transport, rearing) to key sectors of development of the district with loss of human lives. Urban flooding is a major constraint to development and puts people at risk, especially those living in rapidly expanding cities in developing countries. This work aims to analyse the trends of extreme rainfall events through the calculation of rainfall indices to provide the necessary tools for implementing adaptation strategies to this phenomenon.

Materials and Methods

Area of Study

Located in the south-east of Côte d'Ivoire, the District of Abidjan (see Figure 1 for the Map of Abidjan District) lies between latitudes 5°10' and 5°30' North and longitudes 3°45' and 4°21' West. It comprises ten (10) municipalities plus three sub-prefectures (Bingerville, Songon and Anyama). The average rainfall into the Abidjan district varies from 23 mm for the least rainy month (January) to 525 mm for the wettest month (June). Abidjan's climate is humid sub-equatorial and is characterised by two great seasons alternated by two short ones: a great rainy season (March-July), a short dry season (August-September), and a short rainy season (October to November). And the last is the great dry season which runs from December to March.

Meteorological data

Uninterrupted daily precipitation data for 40 years (1981–2020) from satellite imagery database from UC Santa Barbara. The data used are daily rainfall amounts with a spatial resolution of 0.05° (5 km * 5Km) and are of CHIRPS and CHIRTS origin. Their choice is based on their wide use and accessibility.

Software and data quality analysis

The methodology adopted in this study to analyse extreme rainfall events is that of climate indices (refer to N'Guessan Bi et al., 2018; Aguilar et al., 2009; Hountondji et al., 2011) proposed by the Expert Team on Climate Change Detection and Indices (ETCCDI) from the ClimPACT 2 Master programme. ETCCDI experts have defined 27 climate indices, 11 characterise rainfall and 16 extreme temperatures. However, in this study, only five indices characterising rainfall extremes are selected, namely the total annual rainfall (PrcpTOT), the total annual rainfall on very wet days (R95p), the percentage of total annual rainfall on very wet days (R95pTOT), the total annual rainfall on extremely wet days (R99p) and the percentage of total annual rainfall on extremely wet days (R99pTOT).

Results and Discussion

Interannual evolution of cumulative rainfall index trends in Abidjan district from 1981-2020

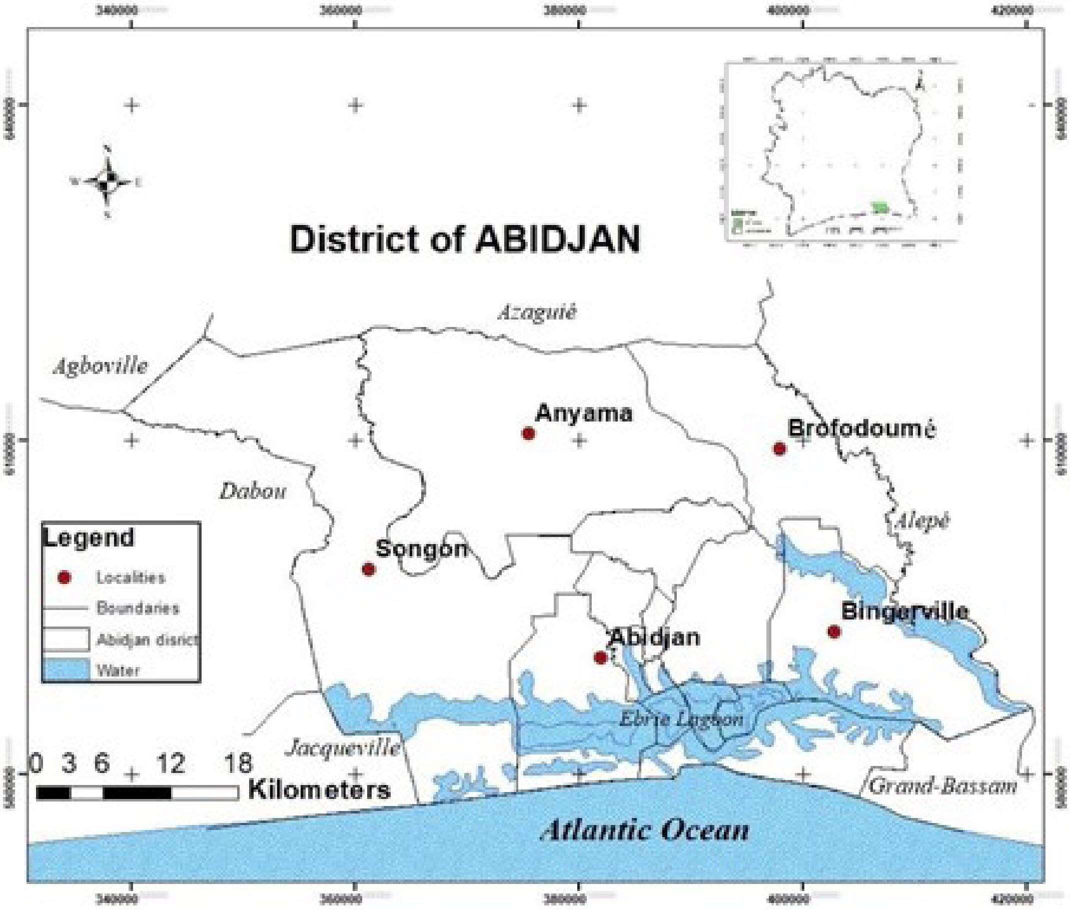


Figure 1: Map of Abidjan District

Total annual rainfall ranges from 1195.71 mm to 1952.58 mm, with an average of 1623.30 mm. It has increased by 3.15 mm/year with significant peaks in 1999 and 2010 (see Figure 2 and Figure 3).

Cumulative heavy rainfall amounts range from 135.696 mm to 813.94 mm, with an average of 333.946 mm. They decreased by 0.39 mm/year with a significant peak in 1982. They decreased by 0.029%/year with a significant peak in 1982.

Cumulative heavy rainfall amounts range from 8.38 mm to 328.47 mm, with an average of 102.041 mm. They decreased by 0.65 mm/year with significant peaks in 1982 and 2014. Their contributions range from 0.70% to 17.87%, with an average of 6.21%. They decreased by 0.060%/year with significant peaks in 1982 and 2014.

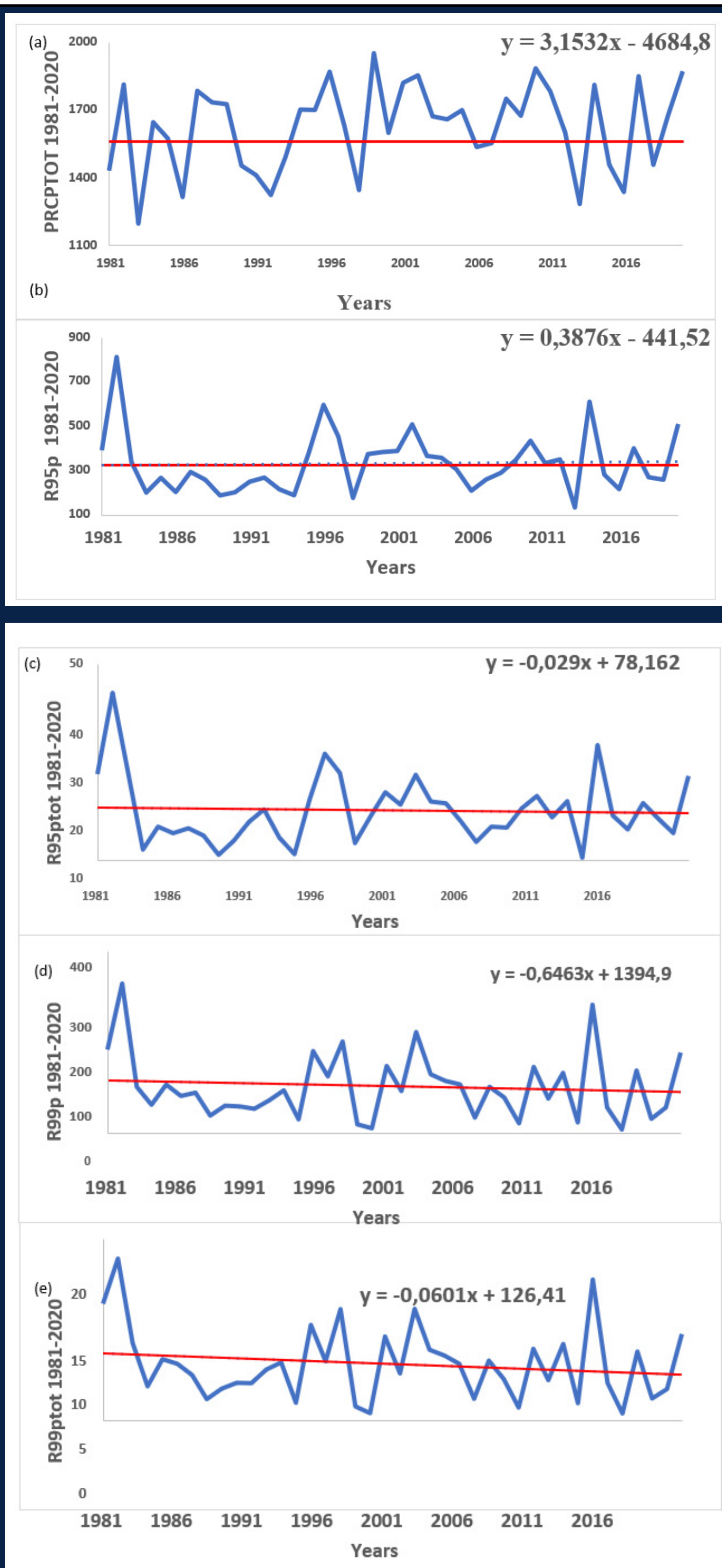
This study shows the evolution of extreme rainfall trends by calculating total annual rainfall indices (PrcpTOT) and frequency indices in the Abidjan district from 1981 to 2020. The statistical analysis of rainfall trends indicates an increase in PrcpTOT over the entire study period. They grow by 3.15 mm/year with an average of 1,623.304 mm. Concerning the frequency of intense and extreme precipitation, there is a decrease of 0.29% and 0.6% per decade. Still, 20% of total rainfall is intense, and 6% is extreme. The remaining rainfall is fine rain, often spread out over time. This could be due to the fact that the South receives more rainfall due to its geographical position, unlike the North, which has a higher contribution. A 4.45% drop in rainfall over the last two decades is also observed in terms of frequency.

These results are similar to those of another study in the Goh region. They showed that the region experienced a decrease in both rainy day heights (R95p) and rainfall frequency (R95pTOT) over the period 2000 to 2009. This fact suggests a general decline in frequency indices in the sub-region as the same observation was made by a previous study from 1991 to 2018. Increasing rainfall frequencies coupled with rainfall intensities favour flooding. During the first two decades, rainfall was intense, and it was only after the frequency of rainfall increased in the 1990s that flooding began to be more significant. The frequency of intense rainfall is said to be decreasing in favour of extreme rainfall.

Conclusion

Analysis of trends in 5 extreme precipitation indices from 1981 to 2020 (40 years of observation) revealed that rainfall (intensity) that had been decreasing has picked up in recent years. The frequency of rainfall is an important factor in triggering flooding. The decreasing frequency of intense rainfall in favour of extreme rainfall indicates that attention should be paid in the coming years to the intensity and frequency of rainfall, which should also increase.

Figure 2. Inter-annual trends of PrcpTot:
(a) R95p;
(b) R95pTOT;
(c) R99p;
(d) R99pTOT;
(e) from 1981 to 2020.



Abidjan's City Center, Ivory Coast (Getty Images/aroundtheworld.photography

4. Investing in Sub-Saharan Africa Water Resources; Technology vs People

Harriette Adhiambo Okal, Denis Hughes, Jane Tanner

High-risk decisions on water resources development and management are being made across Sub-Saharan Africa (SSA) based on scarce data and unreliable information. The outputs from global models are increasingly being used to make decisions on water resource development and management. However, studies show that global hydrological model outputs are not being sufficiently validated and are therefore unreliable. Subsequently, there is evidence of environmental and socio-economic risks to water users, riparian zones, aquatic biodiversity, and funding institutions when developmental projects are based on these unreliable data and model outputs.

The data scarcity and unreliability include missing, inconsistent and irregular data, costly and restricted access to available records, absence of information on water use patterns, scanty and lack of hydrometeorological and hydroclimatic monitoring networks within River Basins (RBs), as well as a lack of local modelling frameworks generating hydrological data.

Epistemic uncertainty stemming from lack of understanding of the hydrological dynamics and parameters also remains a challenge in water resource science within the region. This is substantiated by the majority of available hydrological assessment studies conducted by non-Africans. The resultant limited local expertise fostered in data generation, development and setups of global and regional models, and interpretation of outputs is a threat to achieving sustainable hydrological monitoring and assessment, and with the anticipated projections in water demand, development, and climate change is increasing risks to the environment and people.

A systematic literature review conducted by the authors on hydrological modelling studies from 2000-2022 within SSA's 12 major RBs; Congo, Nile, Ganane, and Rufiji representing the Eastern and Central SSA (SSAEC); Senegal, Lake Chad, Volta, and Niger for the Western SSA (SSAW); and Limpopo, Okavango, Orange, and Zambezi representing the Southern SSA(SSAS), showed that region suffers from unreliability of ground-based observations. The results revealed that only 11 of the 71 studies within SSAEC, 9 of the 78 in SSAW, and 10 of the 56 in SSAS used in-situ data for modelling. In addition, the lack of local capacity is highlighted as 46 of the 71 in the SSAEC, 55 of the 78 in the SSAW, and 27 of the 56 in the SSAS showed no African institution was involved during the modelling and monitoring processes (Figure 1).

Global Hydrological Models (GHMs) have become substitutes for monitoring and assessments within SSA owing to the aforementioned ground data scarcity, and epistemic uncertainty with large resources pulled towards their development and advancement. The GHMs, which typically use global datasets from satellite products, are increasingly being employed to extrapolate outputs for applications at the basin scale. However, the success of GHMs both at basin and sub-basin scales is still debatable as different models produce different results even when applied in the same basin. Invalidated outputs, misinterpretation of localized scenarios, and poor performance present remarkable debates on the suitability and credibility of these GHMs applications. Studies show that without ground truthing and validation, these resources-GHMs and satellite data are unreliable.

Conclusion

Data scarcity and low levels of local capacity development within the hydrological community in SSA pose threats to sustainable water resources assessment and management. Although it is recognised that local hydrological data is often scarce, fallible, and difficult to obtain, it is argued that the investment into the maximisation of the available data is as important as the investment into the development of global models and fine-resolution satellite products. Therefore, efforts and investments by stakeholders and regional agencies into building local competency in developing regional hydrological models is to be stimulated. Investments that build local capacity are challenging but will result in longer-term effective returns for sustainable and climate-resilient water resource management within Sub-Saharan Africa.

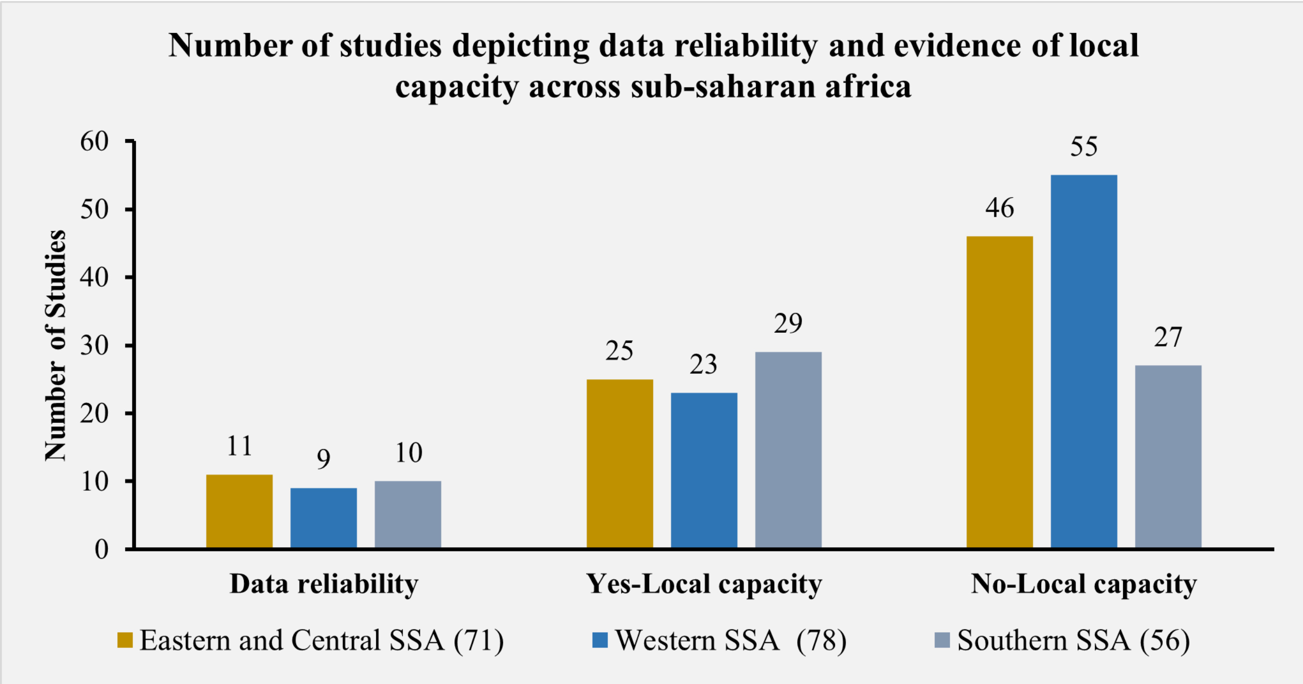


Figure 1: Graphical representation of data reliability and evidence of local capacity built from hydrological modelling studies across Sub-Saharan Africa

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