Enabling Resilient Economies:

An Interim Report for Catalyzing Prosperity and Structural Transformation Through Water Resilience

The **Water Resilience for Economic Resilience (WR4ER)** initiative works to inform the principles, theories, tools, and practices for ensuring that financial and economic institutions can manage and invest in building resilient economies that will endure and thrive amid a shifting climate.

WR4ER efforts are dedicated to defining the practice of water resilience for economic planning, evaluation, and management by aligning our existing activities and messages and developing new, common tools and approaches to enable water-centric economic resilience principles. More at **www.wr4er.org**.

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For Cees van de Guchte, who was one of the inspirations and creators of the WR4ER initiative. More importantly, he was a tremendous colleague and friend.

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Executive Summary

This interim report and the associated cases are designed to showcase the need and guide the transition towards redefining economic prosperity in a time of increasing uncertainty. Our key insights:

1. Resilience to deeply uncertain future events must become an economic objective, including but not limited to risks around irreversible climate transformation, and ranging from macroeconomic planning to project feasibility and implementation scales.
2. Water resources are at the center of resilience. Water constitutes an economic flow between projects and sectors and across political, social, administrative, trade, and ecological boundaries. Water resilience can serve as a tool for coherence across these boundaries. Treating water as a fixed input can create systemic risk.
3. The past can no longer reliably predict future water conditions. Assuming stability in water resources and inputs can in fact destabilize long-lived infrastructure, policy frameworks, and regulatory systems as well as widespread economic decision-making processes.
4. Economics can define if an investment, project, or policy is a "good value," but traditional analytics discount and discourage most enhancements designed for adaptation, flexibility and resilience.
5. In many cases, growth measures are correlated with increasing water consumption. Decoupling economic growth and water use while coupling water sharing are strategic tools for reducing sectoral water shocks and ensuring sustainability.
6. Fiscal, monetary, and regulatory policies and incentives can be mobilized to accelerate the water-resilient investment, transparency, and tradeoffs necessary to enable economic resilience.
7. De-risking can incorporate a climate adaptation perspective to buffer limited shocks and stresses, while resilience extends to the ability to reorganize systems, targets, and institutions and make course adjustments despite deep uncertainty to ensure prosperity and sustainability.
8. We must quantify, measure, and track resilience to inform decision making, but water quality and quantity are by themselves insufficient measures of water resilience; they are rarely reported to show trends over time or to include measures of confidence, change, system evolution, and uncertainty.
9. We can expand economic analysis to accelerate and mainstream water resilience to ensure that we properly value the robustness and flexibility needed for resilient economies, communities, and ecosystems. The examples and evidence already exist. Adjusting tools such as cost-benefit analysis, net present value, and discount rates can promote resilient investments, narratives that support long-term sustainability, climate equity and justice despite a dynamic water cycle, and sharing risk between stakeholders and sectors.

PART 1

Introduction

Major scientific and advocacy organizations regularly publicize alarming maps that show "hot spots" — regions and countries highlighted to show that dire climate impacts are occurring in these regions. We are told that these impacts in these regions are economically important and should influence key economic and financial decision-makers such as credit organizations and insurance companies, that these impacts have serious equity effects, and that they require immediate, dramatic action.

The gap between climate science and economic planning and investment decisions, however, has remained largely unbridged. High profile analyses such as the Stern Review forecast the economic damage that climate change could inflict without rapid decarbonization (2007). Our transition to cleaner energy is underway, but is occurring much later and less comprehensively than climate scientists advised. At the same time, the fingerprints of already severe climate impacts are also ahead of schedule. Should the regions on these maps that are coded yellow or green be less concerned than the red zones? Indeed, climate science has proven good at warning but less useful in terms of effective forecasts useful for planning, prioritization of investments, and technical decision-making processes that have traditionally required precision and accuracy. These risk maps are at best an unfocused snapshot, and they may mask as much risk as they reveal.

Resilience is not an accident — it must be planned for and invested in, at different spatial and geopolitical scales. But resilience has not yet emerged as an economic objective, much less the need for recognizing the role of water as the medium of climate resilience and as a catalyst for the needed structural transformations. Many technical disciplines have begun to address these issues through major shifts, especially engineering and hydrology. Finance is creating new instruments to allocate funds, ensure long-term investments, and pool, transfer, and share risks. In theory, labeled climate finance should be a key solution, especially for middle- and low-income countries, yet nearly 90% of total climate finance is dominated by mitigation and only 3% goes to developing areas like Africa (CPI, 2020). Increasing amounts of financial resources are being mobilized by private and public initiatives oriented towards economic transformations such as the clean energy transition, the digital transformation, and the extended use of nature-based approaches to manage services for cities and rural areas. These and other fields have identified resilience as a new technical and operational framework as a way to move beyond reducing climate risk to specific threats and to move towards approaches that ready our communities, economies, and ecosystems for a broad spectrum of both known and uncertain change.

Defining Resilience

The concept of resilience is relatively recent and builds on earlier terms. Climate adaptation is a well-established approach, which can also include climate proofing and climate de-risking. Climate adaptation is a broader and related concept that ensures that the essential functions of a sector, project, or asset are prepared, responsive, and can continue despite particular climate impacts. The effects of an extreme event or long-term decline in water availability can be assessed and compensated for through built systems, governance, regulations, nature-based solutions, and so on.

Resilience is a state that can follow from effective climate adaptation, but resilience also extends beyond de-risking and climate proofing. Resilience includes the capacity to reorganize in order to sustain social wellbeing, such as aspects of an economy, institutions, private firms, the values of individuals, and social and cultural expectations in response to transformational changes now occurring as a result of climate change and other pressures.

The pace and scope of climate change — quickening sea-level rise, extreme fire events, tropical cyclone activity, permanent loss of snowpack and glaciers, shifts in the water cycle — result in ecological changes that fundamentally and in most cases irreversibly alter our landscapes. Resilience is the ability to ensure that human, social, and economic systems can also reorganize. For instance, the effects of an extreme event or long-term decline in water availability can be assessed and compensated for through built systems, governance, regulations, nature-based solutions, and so on.

Resilience differs from sustainability, but not radically. The latter emphasizes the need to balance economic, social, and environmental factors in order to meet the needs of present and future generations. The first focuses on the need to thrive and reorganize despite experiencing fundamental environmental change and deep uncertainty.

Resilience as an Essential Economic Concept

Economics has been the definitive guiding science of development for decades, informing decision-makers at all levels on how to build wealth and prosperity. Yet, economists have proven to be quite optimistic about climate change.

Macroeconomic models and analysis normally develop only short- and medium-term predictions about the structural changes of the economy and serve to analyze the impacts of specific macroeconomic policies and investments, especially public investments. General equilibrium models also analyze the direct and indirect effects on the economy of these structural changes. Most economic models assume a steady-state environment and rarely consider changes in weather conditions, water availability, or changes in the environmental conditions that are assumed as given and constant through time. Scarcity or water variability are rarely a restriction to be taken into account in decisions on future development pathways and the balance of payments. In practice, the assumption in macroeconomic planning is that water is unlimited, its availability and quality are stable, and that water changes will not affect the structure of the economy and the model of economic growth or trading patterns. Water is usually treated as a simple production “input” rather than as a “flow” of resources and productive capital derived from climate, hydrological processes, and ecosystems, which can itself be regulated, modified, depleted, or depreciated.

Traditional economic analysis tools serve to evaluate programs and investments by comparing alternatives and optimizing tradeoffs between competing uses for scarce resources, such as by maximizing Net Present Value (NPV), Economic Internal Rate of Return (EIRR), or by assessing outcomes through cost-effectiveness and low-cost analyses. At both macroeconomic and project feasibility levels, these tools tell us if an investment is “good.” Implicit in these evaluation tools and macroeconomic models, however, is that climate conditions will remain broadly similar to the time of analysis. Climate change violates these assumptions in profound ways. Widespread responses include: a) assuming that uncertainty can be reduced to comparable indicators such as expected returns, the frequency of extreme events, average and dispersion measures, and other variables by using data from the past to understand the risks we face in the future, or b) discounting uncertain and/or distant climate impacts, such as shifts in the frequency or intensity of extreme weather events or shifts in the timing and form of precipitation. But irreducible uncertainty is an integral part of any future scenarios that recognize the impacts of climate change. Strategies such as adaptable pathways, diversification, no regrets options, nature-based approaches, and contingent water allocation rules are all methods to prepare for many alternative futures.

An increasingly widespread approach is to include specific climate and non-climatic impacts in de-risking project development. De-risking has been an important advancement that can ensure that an investment, policy, or sector will maintain acceptable performance levels against an array of different conditions. Often, de-risking results in modest but significant changes to an investment to maintain feasibility. However, these changes may also be insufficient to establish resilient frameworks for societies and economies to prosper over time given the progressive pace of climate change. Thus, de-risking may fall short as a tool, especially at macroeconomic and planning levels. We can confidently expect dramatically different climate conditions on time

and spatial scales that, for economic planners, are quite rapid. Fast sea-level rise, extreme heat and fires, and flood and drought events that compare with distant centuries will accelerate.

Ignoring these impacts or assuming that alternative, unplanned-for solutions will emerge is unrealistic. Worse than that, such an optimistic view amounts to believing in spontaneous adaptation responses that match the scale and scope of the challenges just in time instead of assuming that adaptation and resilience are the outcome of planned and coordinated efforts.

Like security, resilience is a non-rival and non-excludable public good that can only be provided through collective and coordinated actions. Indeed, the emerging practice of climate resilience across a wide range of technical disciplines suggests that over-efficient, highly optimized solutions may also be "brittle" when confronted with events that have been deeply discounted. Major projects and sectors may be prone to systemic failure if key assumptions are violated and not tested for their sensitivity in advance. Traditional analytics discount qualities such as redundancy, robustness to a range of multiple futures, or flexibility — components that are emerging as central qualities for resilience in other disciplines.

In contrast, economic resilience ensures that we are maximizing benefits across a dynamic set of climate and non-climatic conditions. In practice, economic resilience may reduce "efficiency" in the short term as we anticipate both high-confidence impacts as well as less certain, long-term, and indirect impacts. However, over the medium to long term, efficiency will increase, as risks fall and progress and sustainability are enhanced in a larger array of circumstances.

At the level of a central bank, economic resilience may mean that energy and data systems have independent inputs, and that critical infrastructure systems can operate across a wide span of climate conditions over their operational lifetimes. Resilience bears an upfront cost, but with considerable long-lasting benefits.

Why Water is Important to Resilience

Water, especially freshwater resources, have become a central focus for climate adaptation and resilience, in no small part because freshwater management has been one of the key enabling aspects of economic development.

Clean, abundant freshwater is central to drinking water and human health, but water is also critical to the overall economy. Almost all forms of agriculture and the food system, energy production, manufacturing, transport, tourism, and other resource management sectors are highly dependent on freshwater resources. The services water provides are dependent on the good water status of water bodies. Water is often critical for data and intensive computation, especially in high-tech industries. Water has also been called the medium through which most of the negative impacts of climate change will be felt. Indeed, some 74% of natural disasters between 2001 and 2018 were water-related, including storms, droughts, and floods, affecting over three billion individuals (UNICEF, 2022).

As early as 2009, the scientific community pointed out how long-standing assumptions that the past could predict future water conditions were no longer true — let alone useful — for technical planning, design, and operations for facilities and projects that considered any aspect of the water cycle, particularly water sector infrastructure. By 2012, a team led by the World Bank referred to these challenges as "deep uncertainty," when planning and design could not even reasonably distinguish between the likelihood for drier or wetter futures.

Teams spanning institutions such as the Rand Corporation, Deltares, OECD, the US Army Corps of Engineers, UNESCO, and the World and Asian Development Banks have subsequently established structured decision-making procedures to compensate for at least some of these water uncertainties in project-level feasibility and de-risking studies. Collectively, they point to several core aspects of analytical climate resilience:

- Risk assessment should consider both high- and low-confidence climate impacts.
- Robustness to an array of plausible futures and decisive interventions to high-confidence impacts remain an essential component of resilience.
- Planned flexibility and adaptability, and long-term temporally staged structured decision-making to accommodate the uncertainties associated with long-lived infrastructure, resource management, and governance and regulations are essential to address a broader array of credible, diverse futures. Flexibility is a newer, less familiar component of resilience.
- Stress testing water-related climate and non-climatic impacts and shared and cross-sectoral water relationships is essential to cope with ongoing climate stresses and long-term transformation.
- Most of our current tools for evaluating and approving investments discount or ignore these aspects of resilience in economic and quantitative terms.

Given the inordinate role that water plays in expressing adverse climate impacts, many groups have begun to recognize that water may also be the key medium for climate resilience. The most recent notable voice in this area is the IPCC, which has recently called for the widespread implementation of "water-based adaptation" in order to ensure that resilience captures the connective, cross-sectoral, and integrative qualities of water resilience.

In fact, many disciples are actively responding to these insights, which is itself leading to quite innovative approaches to go beyond seeing risk and to enable decision-makers to directly invest in resilience. Indeed, over time we may be seeing resilience emerge as a new, enabling economic sector in itself as these concepts develop.

Who Needs Economic Resilience?

The Water Resilience for Economic Resilience (WR4ER) initiative is designed to advocate for water resilience as an economic principle for macroeconomists, economic planners, central bankers, and finance and development ministries — as well as the groups that interact with these audiences, such as insurance and reinsurance programs and companies, city planners, corporations that operate or depend on critical infrastructure, and funders and designers of critical infrastructure programs, including development and commercial banks.

These groups are not traditional “water audiences,” nor have many of these institutions normalized resilience. In most countries, these groups have identified climate change as a driver primarily relevant to transitions in energy production and decarbonization.

Conceptually, economic resilience at these levels includes diversification, coherence in water use across sectors, and robustness and flexibility built into critical parts of the national economy. However, we also believe that there are more detailed, quantitative, and structured socio-economic interventions to foster water for economic resilience that should be considered, which are detailed in Part 3.

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PART 2

Case Studies: Implementing a Water-Centric Approach towards Resilient Economies

The majority of this report consists of a series of global case studies intended to make the case of the importance of water resilience for the economy and for economic agents and decision-makers in a specific country or at subnational / regional level. Are economic decision-makers considering how shifts in the water cycle represent both a strategic, even systemic risk to many sectors and the economy as a whole? Are water resources and its services being identified as a medium for national, regional, and sectoral economic resilience?

There are multiple ways on which water scarcity and competition and water security can impact economic activity, economic structure, employment, inflation, the balance of trade, the financial and insurance system, and key economic indicators that provide insights into planning, monitoring, and evaluation at national, subnational, and supranational levels. In part, our goal is to see where progressive insights are appearing that can inform economic decision-makers more broadly.

The following cases illustrate the importance of water resilience for the economy by focusing on key policy areas as diverse as rural development, energy policy, taxation and prices, land planning, environmental and social policies, and climate change adaptation, among others.

Angola: Moving from an Oil-Based Economy to Water-Centric Resilience

Excerpted from:
World Bank Group. 2022. *Angola: Country climate and development report*. CCDR Series. Washington, D.C.: World Bank Group.

Key Messages

- Water resources are the pillar of climate resilience for Angola. Climate-related hazards such as flooding, coastal erosion, and droughts are hindering Angola's economic development, and the situation is expected to worsen with climate change. Southern Angola has experienced a severe and prolonged drought over the last decade, leading to high levels of food insecurity and water scarcity for millions of people.
- In Angola, agriculture and energy are critical sectors that require urgent attention to build climate resilience and ensure inclusive development. Angola heavily relies on hydropower, making it particularly vulnerable to climate change impacts, and over half of the population lacks access to electricity.
- Total economic losses due to drought in agriculture may rise from as much as US$ 100 million per year nationwide today, to more than US$ 700 million per year by 2100. The productivity of fisheries is also projected to decline, with the maximum catch potential expected to decrease by 43.7% by 2050 and 64% by 2100.
- The Ministry of Finance and the Ministry of the Economy and Planning should collaborate

to create a fully costed plan for resilience investment. This will require coordination across the government and the allocation of limited resources to ensure that all sectors achieve resilience. Before committing to large investments, sector ministries will need to understand the tradeoffs between investment choices and develop a portfolio of climate resilience projects with identified public and private financing sources.

- Angola is reforming its water sector, creating the independent Regulatory Institute for Energy and Water Services (IRSEA) and the National Water Resources Institute (INRH). The country also lacks basin councils and needs to implement and improve water resources management frameworks to prepare for droughts and floods. Institutional capacity remains weak and needs to be improved at key administrative levels.
- Building the resilience of Angola's water sector requires a multifaceted approach: 1) strengthening the WRM framework and investments in water storage, 2) ensuring the sustainable operation and maintenance of infrastructure, 3) strengthening provincial water and sanitation utilities, and 4) investments to expand water and sanitation access to these plans.

Introduction

Climate change is already affecting people's lives and livelihoods in Angola, as well as the Angolan economy. The country is experiencing increasingly severe and frequent climate hazards — including the South's worst prolonged droughts in decades. Climate change impacts also come with a heavy price tag: climate-related disasters (e.g., floods, storms, droughts) cost Angola nearly US$ 1.2 billion between 2005–2017, and on average droughts alone affect about a million Angolans every year. Impacts of climate variability on Angola's water resources are expected to be particularly severe and will affect food and energy production, as well as hydropower, on which Angola relies for most of its electricity.

Angola has significant renewable capital, including agricultural land, forests, water resources, and, above all, its people, who can facilitate this process. But climate change also threatens these renewable assets, and necessary investments in

Angola's Nationally Determined Contribution

Angola is a party to the Paris Agreement and in 2021 submitted an updated Nationally Determined Contribution (NDC). Also in 2021, Angola submitted a detailed Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC). Angola's greenhouse gas (GHG) emissions account for less than 0.21% of the total global GHG emissions. According to the country's updated NDC, its total GHG emissions in 2015 were 99.99 million metric tonnes (Mt) CO2e or 3.74 tonnes per capita (Republic of Angola, 2021), which is lower than the global average of 6.39 tonnes per capita for that year (Climate Watch, 2019). Based on global GHG emissions of 46.87 billion tonnes (Gt) CO2e in 2015, Angola's emissions would constitute about 0.21% of the total global emissions according to their own estimates.

climate resilience will be critical to realize their potential.

To inform the source report for this case study, a robust climate science impact analysis was undertaken, followed by in-depth analysis of macroeconomic and sectoral implications of climate impacts on Angola's future development prospects. The report was developed over the course of a year, leveraging technical teams from across the World Bank, the International Finance Corporation, and the Multilateral Investment Guarantee Agency, working in close partnership with the Government of Angola through its Ministry of Economic Planning and other key climate-sensitive sectoral ministries.

Current Economic Context

Angola's oil-based economic growth of the past two decades has not delivered inclusive development and is now losing steam. After the end of a 27-year civil war in 2002, Angola enjoyed several years of robust, if uneven, economic growth, led by oil exports. In 2021, national accounts show the oil sector still contributed 27% of gross domestic product (GDP) in 2021. In the meantime, around 50% of the Angolan labor force are employed in agriculture, predominantly as subsistence farmers. Despite agriculture only contributing approximately 9% to the country's GDP and utilizing just one-third of its five million hectares of arable land, it remains the occupation for 51% of the country's labor force.

Angola's development priority is therefore to use the revenues from its dwindling oil wealth to diversify its economy, reducing its dependency on the petroleum industry and creating opportunities for sustainable growth and job creation. As of 2020, it was the eighth-largest economy in Sub-Saharan Africa, but still categorized as a lower-middle-income country, with gross national income (GNI) per capita of US$ 2,140. Recognizing this challenge, Angola's President has stated that diversification is "a matter of life or death" for the country, and the next National Development Plan (2023–2027) features economic diversification as one of three focus areas (along with human capital and infrastructure).

Angola's 2018 Systematic Country Diagnostic identifies agribusiness, fisheries, and manufacturing as potential (non-extractive) industries where Angola's economy could diversify and create more employment opportunities. The potential of these sectors is also acknowledged as part of the most recent Country Private Sector Diagnostic by the International Finance Corporation (IFC).

Climate Change in Angola: Impact on Economic Development

Angola's economic development is being hindered by climate-related hazards such as flooding, coastal erosion, and droughts, which are expected to become more intense with climate change. Southern Angola has experienced a severe and prolonged drought over the last decade. This has resulted in high levels of food insecurity where an estimated 3.81 million people in the six southern provinces have reported insufficient food in addition to water scarcity for over 1.2 million people. The previous severe drought in 2015–2016 led to 80% of existing boreholes becoming nonfunctional due to water scarcity and disrepair.

Climate change is not just a future threat, but already a reality in Angola. Total economic losses due to drought in agriculture may rise from as much as US$ 100 million per year nationwide today, to more than US$ 700 million per year by

2100. The productivity of fisheries is also projected to decline, with the maximum catch potential expected to decrease by 43.7% by 2050 and 64.0% by 2100.

With southern and southeastern Angola projected to become dryer, hydropower production on the Kunene River, for example, is expected to decline. Meanwhile, in urban areas — where two-thirds of Angolans already live, and a majority of jobs are — climate change is likely to exacerbate water scarcity, bring more intense storms and coastal flooding, and increase the risks associated with inadequate sanitation. Sea-level rise is expected to have a significant impact on coastal settlements in Angola, where more than 50% of the population lives, affecting housing, roads, and industrial and commercial infrastructure.

Heat waves are another threat Angola faces. A recent study of over 150 large African cities predicts that heat waves, exacerbated by the urban heat island effect, will expose 20–52 times more people to dangerous heat conditions by the end of the century. Luanda is among the five most exposed cities, with the highest increase in relative terms compared to the historical period. The city has less than 1 m2 of green space per capita, much lower than comparable cities and the recommended 9 m2 by the World Health Organization. The urban heat island effect is expected to increase energy costs related to air conditioning, air pollution levels, and heat-related illness, and mortality and is projected to worsen due to climate change.

Moving Towards Resilience: Defining a Strategy

Five pathways have been identified to achieve a vision of a future Angolan economy that is both diversified and climate-resilient, with opportunities for all. Tailored to the national context, these approaches were identified in dialogues with the Government of Angola and build on national development priorities. Angola is rich in natural capital — not only oil, gas, and diamonds, but also abundant water resources, renewable energy potential, and fertile arable land. Therefore, to shift away from an economy driven by oil and gas extraction and toward a sustainable and diversified economy based on renewable natural capital, this Climate Change Development Report (CCDR) recommends investing in and building the resilience of key sectors, notably: 1) water resources, 2) agriculture and fisheries, and 3) renewable energy. Delivering the vision of a climate-resilient and diversified economy also entails 4) enabling green and resilient cities with economic opportunities for all Angolans, and leveraging Angola's young population by 5) boosting human capital, through expanded, climate-resilient access to basic services and fostering a culture of climate preparedness.

Water resources are the pillar of climate resilience for Angola. Angola is endowed with plentiful water resources that, if well-managed in the context of climate change, can produce clean electricity, abundant food, and livable cities. Angola's vast water resources are unevenly distributed. Seasonal and interannual rainfall variability is high and floods and droughts have been part of a natural cycle that is expected to intensify with climate change, leading to a decrease in overall water availability.

To achieve water resilience, the source report recommends: 1) strengthening basin water management offices and councils to balance competing demands with limited and variable water resources, 2) investing in water storage, including groundwater and watershed storage (i.e., nature based solutions) to mitigate flood risks and store water for dry periods, 3) expanding access to clean water and sanitation across rural and peri-urban areas (US$ 2 billion), and 4) rehabilitating and strengthening the operation and maintenance of dams and rural infrastructure to serve productive uses (US$ 1 billion).

In Angola, agriculture and energy are critical sectors that require urgent attention to build climate resilience and ensure inclusive development. Angola heavily relies on hydropower, making it particularly vulnerable to climate change impacts, and over half of the population lacks access to electricity. Expanding electrification and building resilience in the power sector are, therefore, essential to realizing Angola's development vision.

Agriculture in Angola is crucial to food security and holds tremendous commercial potential, but climate change will require significant reforms to realize the sector's potential as an engine of growth. Only about a third of the arable land is cultivated, and only about 2% of arable land benefits from machinery or even animal traction. Irrigation is also rare, and unsustainable practices are common, resulting in forest loss, reduced biodiversity, and other environmental burdens. Angola also has large potential for fisheries and aquaculture, but it needs to carefully manage its resources to protect ecosystems and promote sustainable growth. Overfishing and changes in hydroclimatic conditions have greatly affected the sector.

Without effective adaptation, climate change is likely to have a major negative impact on agriculture — and thus food security. To build the resilience of food systems to rising climate shocks in Angola, the CCDR recommends scaling up climate-smart agriculture practices and climate-smart fisheries technologies, rehabilitating old irrigation perimeters and infrastructure left in neglect following the civil war, and building flexible, decentralized systems for farmer-led irrigation development, while also expanding extension services support and repurposing agricultural subsidies to benefit all farmers.

Cities can be catalysts for growth and job creation, but they need to be resilient, livable, and inclusive to realize this potential. Two-thirds of Angolans live in urban areas, and by 2050, the share is expected to rise to 80%, with cities hosting three times as many residents as they do today. To promote clean, compact, and connected urban development in Luanda and secondary cities, the CCDR recommends investments in comprehensive solid waste management systems to curb methane emissions, reduce flooding, and improve quality of life. Local governments will need to coordinate and lead implementation of urban resilience measures — such as risk analyses, integration of risk maps into territorial plans, and inspection and enforcement of zoning regulations. Flood early warning systems, especially for coastal zones, and nature-based solutions for flood and landslide protection, will also be critical measures to live with rising climate risks.

Finally, social and cultural capital are critical for Angola's future. Angola's most important wealth is its people, who are young (the median age is 17) and can power climate-resilient development across sectors — but only if they are healthy, well-nourished, and properly trained. The creation of a culture of climate preparedness, especially through education reforms, will contribute to enhancing national capacities for climate resilience. In order to raise a climate-conscious generation, it is critical to start in the early years and instill values of shared responsibility and environmental stewardship in primary education. As Angola prepares a new strategy for its tertiary education sector, prioritizing programs that prepare workers for careers in adaptation and low-carbon technologies (i.e., “green jobs”) is an opportunity to boost its future competitiveness.

Water Resilience Priorities

A key priority for Angola today is to put climate resilience at the center of all planning, integrating climate risks and adaptation measures into all sectoral plans and strategies, the medium-term fiscal strategy, and territorial planning instruments. Sectoral, national, and subnational planners need to ask, “What new climate risks/opportunities do we need to adapt to, and what can we adapt towards?” The next National Development Plan can propose an integrated package of climate resilience investments, policy reforms, and institutional changes.

The Ministries of Economic and Planning and Finance play a key role and can lead an inter-ministerial coordination structure with specific responsibilities and timelines for line ministries engaged in implementing climate action. Planning is especially critical in the climate-sensitive water sector to address competing demands amid growing variability. Finally, public investment management needs to be strengthened and made more climate-responsive, employing mandatory assessment of new investment projects in line with national climate priorities.

Key government institutions should be empowered to tackle the climate crisis and ensure adequate financial and human resources. Professional and well-trained staff and adequate resources are both critical. Across all sectors analyzed in this CCDR, existing capacities will need to be enhanced to tackle the new exigencies of climate risk management. Data are also essential. As such, it will be critical to bolster the National Hydrometeorological Agency (INAMET), mandated to monitor and predict climate risks, as well as related agencies involved in early warning/early action systems.

A culture of proactive risk management and climate preparedness should be promoted. Such a shift is crucial in a world where multiple sequential and often overlapping crises are the “new normal.” As basic services improve, they need to incorporate disaster preparedness plans. Mainstreaming climate-related disaster risk management, including through better early warning systems, will reduce the costs and shorten the response time when disasters hit. Finally, Angola needs to have the financing in place to deal with climate-related disasters quickly when these hit, while avoiding a large diversion of expenditures from its development priorities through financial planning and pre-arranged disaster contingency resources.

A fully costed resilience investment plan should be jointly developed through collaboration between the Ministry of Finance and the Ministry of the Economy and Planning. Because achieving climate resilience is a cross-cutting issue requiring coordination across the government, these two ministries play central roles in strategically allocating limited resources and planning investments to meet Angola’s climate-resilient development goals and diversify the economy. Before committing to large investments, sector ministries will need to fully understand the tradeoffs between investment choices and develop a comprehensive portfolio of climate resilience projects that will achieve the resilience of every sector, with clear public and private financing sources identified to fund them.

Making Water Real: Implementing Water Resilience Investment, Governance, and Practice

Sustainable water management is crucial to human well-being and a vital economic resource for agriculture, energy production, industry, urban development, and the environment — thus Angola's economic diversification and climate resilience. While Angola is rich with water resources, these are unevenly distributed, with a rainfall gradient decreasing from north to south and influenced by topography, with most rain falling on the plateau and very little across the southern lowlands and coastal fringe. In addition, seasonal and interannual rainfall variability is high, and floods and droughts have been a natural cycle, expected to intensify with climate change and leading to a decrease in overall water availability. If Angola is to develop its productive sectors, it will need to make significant investments to strengthen its water resources governance and manage increasing demands on limited and variable resources.

Angola's water sector is undergoing a process of reform. The independent Regulatory Institute for Energy and Water Services (IRSEA) has been created, and a water resources mandate has been set up through the National Water Resources Institute (INRH). The provincial water utilities, IRSEA, and INRH are still maturing and face capacity challenges. Only two basin administration agencies exist, and no basin councils have been created. Water resources management (WRM) frameworks need to be implemented and strengthened to set the foundation for drought and flood preparedness plans. Yet, institutional capacity remains too weak to operationalize them at key administrative levels.

Building the resilience of Angola's water sector requires a multifaceted approach: 1) strengthening the WRM framework and investments in water storage, 2) ensuring the sustainable operation and maintenance of infrastructure, 3) strengthening provincial water and sanitation utilities, and 4) investments to expand water and sanitation access. In order to address Angola's most pressing water needs and ensure the resilience of the sector, this CCDR offers the following recommendations.

Priority Area 1: Strengthen Angola's water resources management offices and frameworks as a key step toward building adaptive capacity.

- Strengthen hydrometeorological monitoring, which is crucial for water management and planning. INRH, INAMET, and GABHIC have worked to improve hydromet monitoring, but problems persist with the functionality of existing stations and data collection. All water utilities should start to systematically measure and record their water resources (e.g., aquifer, production springs, and river levels), to understand variability and detect impacts — including from other users.
- Strengthen licensing and registration of users. INRH is making progress on this with bulk water users, and with World Bank support (the PDISA2 project), a nationwide cadaster of users is being developed. Understanding resource use and demand dynamics through this cadaster will provide important data for water resources planning, allocation, and management.

- Implement the bulk water abstraction tariff ("regime jurídico da taxa de captação de água do domínio hídrico") within the broader Financial and Economic Regime on the Use of Water Resources. Approval of this tariff will help promote the rational use of water resources. It doesn't apply to traditional and livelihood uses, so it will not burden poor households. PDISA2 will support pilot implementation in the Kwanza River basin, and the new RECLIMA project will do the same in the southern basins under GABHIC's administration.
- Develop technical capacity for modeling water resources and allocation dynamics. The systematic use of data to balance water allocation across competing demands will enable more sustainable use of water resources and will be crucial to shaping efficient responses to scarcity.
- Enhance the capacities of the Basin Administration Offices and support the creation of Basin Councils as stakeholder participation platforms. In 2021, the Government mandated GABHIC with managing all three southern river basins, but GABHIC still lacks the capacity to fully implement its mandate, and Angola's other Basin Administration Offices are still to be created.
- Clearly recognize the role of water in achieving key development goals in Angola. As a first step, this CCDR included an analysis of dynamics at the water-energy-agriculture nexus.

Priority Area 2: Adopt a comprehensive strategy for water storage at the basin level, integrating watershed storage, groundwater, and surface storage to maximize climate resilience.

- Promote the adoption of nature-based solutions (NBS) such as soil and water conservation measures, sand dams, and managed aquifer recharge to maximize the "sponge" effect of the watershed, in order to mitigate flood risks and store water for dry periods.
- Invest in groundwater exploration and ensure that existing data are shared, managed, and used to inform projects. Groundwater in Angola is poorly known, and thus poorly managed. Studies are needed on strategic aquifers in the South and nationwide. Angola also urgently needs to digitize and make use of the extensive HIDROMINA colonial archive of hydrogeology.
- Adopt a resilience-by-design approach to align surface water storage and other infrastructure investments with the unique characteristics and dynamics of each basin (Ray and Brown, 2015). Groundwater recharge and storage can be used conjunctively with surface water for flood and drought mitigation purposes.

Priority Area 3: Ensure the sustainable operation and maintenance of water infrastructure as a key element of resilience-building.

- Resources need to be channeled into operationalizing and maintaining existing dams. Technical capacities need to be strengthened, and each dam needs an instrumentation and surveillance plan, an operation and maintenance plan, and an emergency preparedness plan.
- Strong support from the Ministry of Energy and Water (MINEA) is needed to strengthen coordination and management across levels of government and among agencies.

Many irrigation dams are semi-abandoned and lack a designated owner or operator, and/or are in a cycle of neglect and disrepair.

Priority Area 4: Strengthen provincial water and sanitation utilities, and the regulator, to ensure that they are resilient to climate variability and shocks, and improve service coverage in urban and peri-urban areas.

- Provincial utilities have a clear and sustainable business model for service delivery, and they need to be strengthened. Provincial utilities have identified six key measures to improve their climate resilience: 1) protecting and monitoring watersheds and monitoring the resource, investing in knowledge, 2) diversifying water sources and conjunctive use of surface and groundwater, creating buffers to have options in times of scarcity, 3) developing drought preparedness and contingency plans, 4) reducing non-revenue water and increasing efficiency, 5) installing meters and creating customer registries, and 6) good operation and maintenance plans.
- Government efforts to connect urban and peri-urban households to the provincial utilities' supply networks must continue. Transitioning from tanker trucks to piped and metered supply has enormous benefits for beneficiary households and can also reduce GHG emissions.
- Continued support to the Electricity and Water Services Regulation Institute (IRSEA) will ensure well-regulated pricing and a healthy sector. IRSEA is working to reduce non-revenue water and promote an efficient and economic use of water, greater service reliability, and increased capacity to adapt to scarcity. Continue to explore public-private partnerships (PPPs) where they can work, selecting urban systems with a clear business model, well-regulated service, and a reliable customer base.

Priority Area 5: Invest to expand access to water and sanitation services for rural households and build planning and operating capacity in municipalities to reduce vulnerability to climate shocks.

- Household access to clean water is a key factor in resilience to climate change and disaster risks. The household's type of access to water for drinking has significant implications for distributional impacts of climate change on health, education and livelihoods.
- In rural contexts where vulnerability is highest, the consolidation and strengthening of sustainable operation and maintenance models of water supply systems is a priority. Investments in small solar- powered systems and manual hand pumps have proven to be more sustainable than those using generators, representing a win-win for adaptation and mitigation.
- It is important to strengthen municipal capacity to operate and maintain water points, frame local community management efforts, and coordinate backstopping support from the provincial level, in order to increase the functionality of water points. The implementation of Municipal Water Plans will promote the integration of local water supply with local management of water resources and will improve preparedness to droughts and increase climate resilience for households.

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Increasing Water Resilience with Jordan's National Water Master Plan

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Key Messages

- Jordan's economic and social resilience, as well as food security, are challenged by dwindling conventional water resources, population growth, and climate change. The World Bank has estimated up to a 6% GDP loss by 2050 due to climate change impacts on water resources.
- Jordan's water supply comes from rivers (32%), groundwater from underground aquifers (53%), and treated wastewater (15%). However, groundwater depletion is occurring at a rate three times faster than the recharge rate, which could compromise much of the country's infrastructure in the next few years.
- The Third National Water Master Plan (NWMP-3) has enabled evidence-based investment decisions by facilitating the integration of climate change effects into its strategic planning. Its detailed water supply and demand modeling at the municipal level accounts for the diminishing availability of underground water, which was previously presumed to be steady and stable.
- Reusing treated wastewater is an opportunity for Jordan to increase economic resilience. In 2020, treated wastewater contributed by 15% to the total water resources, with 91% being reused in the agricultural sector.
- The lack of coordination among decision-makers responsible for water supply, wastewater treatment,

and treated wastewater reuse is a major obstacle in effective water resources management.

Introduction

Jordan is an upper middle-income country, as classified by the World Bank. Like all economies in the region, the Jordanian economy has been significantly strained by the COVID-19 shock as well as the Ukrainian War. Nevertheless, its recovery is transitioning compared to the previous national crisis. In 2021, the economy experienced a positive recovery compared to the contraction seen in 2020, where the real GDP grew by 2.2%. Positive projections by the World Bank and IMF proceed towards economic growth by around 2.4% up to 2024. Services are the primary contributors to the GDP by 60%. Industry contributes by 25% and agriculture 5%.

Jordan is facing significant challenges in terms of its water resources, which are compounded by the effects of climate change, including more frequent and severe droughts and changes in precipitation patterns that could reduce the amount of water available for use. In terms of water scarcity, Jordan ranks fifth globally amongst the extremely high baseline of water stressed countries (World Resources Institute, 2019). Renewable water supply covers 93 m^3 per capita annually, 400 m^3 below the absolute water scarcity threshold (World Bank Group, 2022). Jordanians, residing in one of the most arid regions globally, are familiar with a weekly household water supply of only 36 hours (Zraick, 2022). Jordan's water supply comes from various sources. Water from rivers such as the Jordan and Yarmouk contributes 32% of the supply. Groundwater from underground aquifers provides 53% and treated wastewater accounts for 15%.

In addition to the impacts of climate change, Jordan is also facing economic and social challenges that make it difficult to build resilience and adapt to water scarcity. The country has a growing population and limited natural resources, which puts a strain on its economy and social systems. For example, groundwater overexploitation in Jordan started in the late 1980s, mainly for agricultural production (Margane et al., 2002). Recent studies using remote sensing show that agricultural water consumption still constitutes around 60% of overall water consumption (Al Bakri, 2021; MWI, 2016). This is largely due to the growing number of illegal wells and is compounded by the utilization of water in industry and manufacturing — predominantly for the chemicals and packaging sector.

Current overuse of groundwater is around three times the rate of actual groundwater recharge. As a result, groundwater levels are declining more than 5 m/year, leading to a continuously shrinking supply of groundwater. Therefore, many of the wells currently being exploited will be dry in the future. In turn, water scarcity further drives up energy demand and costs through the need for additional water pumping from greater depths. By 2040, an average 100 m higher pumping lift, compared to 2018, will be required to extract groundwater. This means that pumping water will require approximately 40% more energy over the same timespan, impacting all economic sectors through rising energy demands.

The growing pressure on Jordan's water security is attributed to several factors that contributed to increased consumption, including a two-fold increase in population to 11 million from five million over the past decade, compounded by the influx of refugees from war-torn neighboring regions. The temperature rise of 1.5–2 °C during the last two decades and the projected increase of 1.5–3.75 °C between 2080–2099 are crucial factors that highlight the significant contribution of climate change, according to UNICEF (2022). This increase has led to Jordan's placement of 73 out of 182 countries in the ND GAIN index for climate vulnerability (ND-GAIN, 2023).

Based on regional climate model results, climate change is estimated to lead to a decrease in groundwater and surface water availability by approximately 15% each through 2040. This decline would result in a countrywide decrease in long-term groundwater recharge from 280 MCM/yr to approximately 240 MCM/yr by 2040. Similarly, long-term surface water runoff would decrease from around 400 MCM/yr to around 340 MCM/yr over the same period (2018–2040). As a result, the internal long-term conventional water resources availability will decrease from current levels of 65 m^3/ca/yr to 46 m^3/ca/yr in 2040. Changes in water quality are also expected, with increased salinity in the aquifers due to lower groundwater recharge and higher groundwater use for agriculture, leading to higher irrigation return flows. This will increase the presence of elements like molybdenum, nickel, arsenic, selenium, and radioactivity (radium), which are detrimental to human consumption and require higher intensities of water treatment and associated costs in the future.

Jordan faces a dual challenge of water scarcity and the mounting impact of extreme weather events, such as heavy rainfall and flash floods. The heightened intensity or frequency of these events can lead to agricultural losses and adversely impact the tourism sector, particularly in the southern region of the country. The resulting damage to infrastructure and the economy is significant. However, these events also offer an opportunity to boost groundwater recharge, which has been largely overlooked in Jordan. Groundwater recharge can be achieved by allowing excess rainwater to infiltrate the ground, replenishing the groundwater aquifers that are a critical source of water for the country. In Jordan, there is a need for integrated water resources management that considers both surface water and groundwater resources, and links between them. Given the increasing frequency of extreme weather events, it is crucial to explore ways to capture and store rainwater in a way that facilitates groundwater recharge.

Creating a National Water Master Plan to Ensure Resilience

Previous planning assumed a constant or even increased availability of renewable water resources, although it was known that groundwater resources have limited availability and are already highly overexploited, while surface water resources are nearly fully exploited. Within the framework of the Management of Water Resources Project, GIZ is preparing together with its three water sector partners — the Ministry of Water and Irrigation (MWI), the Water Authority of Jordan (WAJ), and the Jordan Valley Authority (JVA) — the Third National Water Master Plan (NWMP-3). The primary objective of this plan is to incorporate all the critical factors that affect water utilization in Jordan, including future projections, and their impact on water supply security and overall resilience. It is essential to recognize the direct correlation between water scarcity and economic growth.

The NWMP-3 plan has made it possible for Jordan to integrate climate change impacts into its strategic planning for the first time. To accomplish this, a crucial step was to assess and analyze water supply and demand at the municipal level. This analysis has enabled the country to make predictions about the future and is currently informing its strategic investments in the water sector.

In its Rapid Assessment (GIZ & MWI, 2020) and the Water Resources Volume B of the NWMP-3 (GIZ & MWI, 2021), it is predicted that the production for domestic water supply from renewable groundwater resources (both governmental and private) will decline to 29% of the 2018 amount. The existing supply gap (65%) can only be closed by massively investing into desalination technology. For the first time, the NWMP-3 has succeeded in integrating the impacts of climate change (GeoTools, 2021) and the decline of conventional water resource exploitation into the water sector's strategic planning. The decline of conventional water resources availability and exploitability means that additional water resources must be made available to ensure municipal water supply security. This includes non-conventional resources — predominantly desalination of sea and brackish water — to suffice the demands in 2040. To this end, the Aqaba Amman Water Desalination and Conveyance (AAWDC) project is being developed, which is set to provide an impressive 300 MCM/yr, making it the largest seawater desalination facility in the world.

Economic water demand is the amount of water a household would want to consume at a given water price or tariff rate, depending on that household's socio-economic characteristics. Under a system with supply interruptions, water demand quantities can exceed actual consumption. With the continuing rise in income levels, it is expected that the per-capita water demands in all governorates of Jordan will gradually increase over time, with projections of a 15% increase over 2020 by 2040 — on top of demand growth from the expanding population.

An analysis of household water demands was conducted using a coupled hydro-economic multi-agent model. The water demand estimate was detailed per municipality, and has indicated that households in different governorates would expand their current consumption to a varying degree under a supply system with uninterrupted access to piped water. Households in Amman governorate, for example, would currently be expected to expand their consumption by 12% beyond 2018 levels, whereas most other governorates would see a greater increase, based on lower current supply quantities or higher demands.

Water Allocation Gaps (Water Balance)

The total municipal water demand (supply requirements) was estimated at 621 MCM for all governorates in 2018. The projected demand will increase by 28% reaching 798 MCM in 2040. This increase is attributed to population growth only, if non-revenue water (NRW) will remain at the current level of 53.3%.

Water supply of 476.6 MCM in 2018 has satisfied 77% of the required demand, excluding water use for irrigation through the network (around 5.5 MCM). However, the gap between the remaining water production and the required demand is widening due to an increase in demand and the expected substantial decrease of production from conventional water resources. By 2040, the available production of water resources will satisfy only 36% of the required demand as the remaining production will drop to around 279.6 MCM.

In 2018, only 460.5 MCM could be produced from the existing governmental water resources. An additional 332.6 MCM is required to meet the demand of 2025, and the deficit will increase to 518 MCM by 2040. This gap urgently needs to be addressed through planning of projects for water augmentation.
Although cost-intensive water-loss reduction programs have been implemented over the course of the past three decades, they have failed to achieve their aim. NRW has constantly remained at almost the same level. However, in all cases the impact of reduction in NRW compared with the current situation revealed 4% of recovery for demand coverage. This would amount to 89 MCM in water savings if successfully implemented — a challenge considering the continuous expansion of the network and new possibilities for losses. It is also important to note that the calculation of NRW only considers the supply infrastructure and not the abstraction side.

Wastewater Treatment, Reuse, and Water Supply (WTR): An Opportunity For Enhanced Resilience

Climate induced effects such as extreme heat and water scarcity as well as saltwater intrusion are damaging Jordan´s water and wastewater infrastructure, affecting basic service delivery and leading to low energy efficiency. One opportunity to strengthen water resilience in Jordan is to reuse treated wastewater, thereby decreasing the pressure on Jordan's freshwater resources. A project entitled Wastewater Treatment, Reuse, and Water Supply (WTR) helps to improve the performance of selected water sector institutions in Jordan. This includes WAJ and three water utilities: Miyahuna Water Company (MWC), Yarmouk Water Company (YWC), and Aqaba Water Company (AWC).

The main goals of the project are to enhance the availability of treated wastewater of high quality for restricted agricultural and industrial standards. One aim of the WTR project is that 95% of treated wastewater in nine wastewater treatment plants are following the Jordanian quality standard known as JS 893/2006. Another target is to increase operational optimization of the wastewater treatment plants (WWTPs) and hence reduce electricity consumption by 15%. Further goals include improving the technical and human capacities in the water and wastewater sector, optimizing the use of water resources in Jordan, and increasing the quality and quantity of treated wastewater from the 33 WWTPs all over Jordan.

Jordan faces financial challenges in the water sector. The transmission and treatment of water as well as wastewater is connected to high costs due to the quality of the raw water, which often must be treated. Due to the topographical conditions of the country, the water must be pumped up to the necessary heights using a large amount of energy. Therefore, it is economically important that every cubic meter of water is preserved, which is why Jordan aims to increase the proportion of the population connected to a sewer system from 69% (2020) to 80% by 2030 (MWI, 2016). Also, current water tariffs are too low for the sustainable operation of water utilities. Therefore, the WTR project promotes efficient and effective use of scarce resources in the sector. In addition, heavy rainfall events lead to flooding in winter, which can cause blockage by debris or silting in sewage treatment plants or overflowing of the plants. The absence of rain, on the other hand, results in increased concentrations of pollutants, making biological treatment within the plant less effective.

While water scarcity leads to higher water and food costs, higher water availability would instead lead to lower prices for food and water. Increased opportunities for small-scale farmers can be created, and reducing prices for water for domestic use and irrigation can help to alleviate poverty. As pointed out before, the agricultural sector is most vulnerable to changes in water availability. Around 91% of the treated wastewater is reused in the agricultural sector and in 2020, treated wastewater made up 15% of the total water resources. For example, in the northern governorates, a reuse pipeline system was implemented to substitute 40% of the irrigation water with treated wastewater. The treated wastewater is transported from the Wadi Arab WWTP through a pipeline to the Wadi Arab dam and mixed with freshwater. Eventually, the water is used for irrigation of restricted agricultural sectors in the Jordan Valley and freshwater demand is thus reduced. Further examples for the use of treated wastewater are irrigated golf courses for tourism in Aqaba or the irrigation of urban green areas in the city of Amman.

The use of treated wastewater has an economic importance in several sectors as it supports securing employment, especially in the agricultural and the water sector. Currently, organizational and technical capacities are not sufficient to ensure proper operation of complex WWTPs in Jordan. WTR therefore supports capacity development of utility staff and an improved management of the WWTPs to enhance operational effectiveness, efficiency, and sustainability. An approach known as Technical Sustainable Management (TSM) was introduced, and key performance indicators (KPIs) were developed to enhance wastewater management. The aim of the TSM approach is operational improvement and sustainability. It consists of repeated certification according to defined quality criteria and evidence-based recommendations by the supervisory body to improve wastewater management. So far, nine WWTPs have been successfully certified. Continuous surveys of key technical and financial performance indicators of the wastewater treatment plants show a gradual reduction in energy consumption as well as an increasing improvement in the quality of the treated wastewater. The WTR project also promotes the conducting of Training Needs Analyses (TNAs) that allow targeted capacity development for management and operating staff. As a result, plant operations are improved, and the skills of individual employees are strengthened, providing enhanced career opportunities.

Policy Interventions as Proposed by NWMP-3

The Third National Water Master Plan (NWMP-3) for Jordan proposes a range of policy interventions to improve water resource allocation and management. The following proposed interventions enable the national governments to prepare for climate change and plan for it to streamline resilience.

1. Improve the Water Resources Allocation Plan through national level planning coordination

To enable economic resilience, an improved water resources allocation plan is necessary in Jordan. This plan should clearly allocate the resource to different uses based on comprehensive data and with major coordination among related parties. Currently, allocation and investment planning are done without such coordination and data, leaving some parties behind. Achieving this requires a continuous negotiation process among all related parties, with transparency and information sharing being crucial. However, transparency and information sharing remain significant obstacles in many developing countries, particularly in Jordan.

2. Establish a Water Resources Allocation Committee

A Water Resources Allocation Committee is needed, which brings together all stakeholders, meets on a monthly basis, and determines the required allocation of water for all sectors. However, severe obstacles at the management level must be overcome, as decision-makers often prioritize specific interests and neglect water resources management issues. This often results in a lack of understanding of the reasons behind a decline in water resources, which is sometimes ignored for political reasons. Coordination among managers responsible for projects of water supply, wastewater collection and treatment, and treated wastewater reuse are still an exception rather than the norm.

When conditions were favorable, the project attempted to address these challenges by establishing a Joint Planning Committee. The committee's purpose was to openly discuss proposed projects and conditions, question the feasibility and usefulness of such projects, and identify any inconsistencies in data or assumptions. For instance, it brought groundwater vulnerability criteria into consideration while justifying sanitation projects (Margane & Steinel, 2011). However, this effort faced challenges due to the unfavorable conditions brought about by COVID-19 and the beginning of water sector reform efforts, which led to less coordination among the various units competing over funding.

3. Assess and incorporate the water costs from different supply channels and price them accordingly

Economic resilience considers the cost of municipal, industrial, and agricultural water uses. Drastic actions, as proposed by the NWMP-3, are needed to improve economic resilience when facing drastic changes in conventional water resources availability and exploitation in Jordan.

Appropriately considering the cost of water is important for finding the optimal solutions; however, operation and maintenance costs of water supply systems, wastewater collection and treatment systems, desalinated water, and treated wastewater reuse systems are currently not assessed by WAJ or by the water utilities. In addition, the cost of groundwater extraction through wellfields is also not considered (QADI et al., 2018). Hence, there is a need for policy change and prioritizing the use of cost as the primary criterion to determine which source of water should be utilized in a particular region.

4. Incorporate treated wastewater as an alternative water resource for industrial water consumption

Industrial development has increased in Jordan over the past decade, with industrial activities contributing 28% to GDP in 2018 (World Bank, 2022). The major industries are mining and manufacturing. Phosphate and potash mining, cement production, petroleum refining, and fertilizer production utilize the biggest share of industrial water. The mining sector is the main industrial water consumer (90%) and generates around 8% of national GDP. It is thus highly relevant that the mining sector receives an adequate and stable amount of water.

Alternative water resources availability for the commercial and industrial sectors currently impedes economic growth. The challenge is that in most locations there is no alternative to the use of groundwater. Industrial demand currently is around 40 MCM/yr, or 3% of overall water use. This amount is projected to increase to approximately 72 MCM/yr by 2040 (GIZ and MWI, 2022). Thus far, industrial water supply depends mostly on groundwater (approximately two thirds); however, in many industrial processes, treated wastewater reuse could be an option.

The coordination between MWI and the Ministry of Industry or other related entities in the commercial and industrial sectors is weak and there is no agreed procedure for requests and water resources allocation. This also means no planning security for companies. The MWR project is in the process of defining where treated wastewater could be reused from which WWTP source to strengthen this coordination. Since groundwater use shall be prioritized for municipal use, many industries are moving water-intense activities into Aqaba with plans to use desalinated seawater.

5. Incentivize farmers to use wastewater and create a monitoring system for agricultural consumption

Agriculture has increasingly depended on treated wastewater reuse (Oweis, 2021). Although there is a sufficiently expanded distribution network for reuse, some farmers in the northern and central parts of the Jordan Valley still prefer not to reuse treated wastewater. In the highlands, as of 2020 there were 370 signed agreements for treated wastewater reuse around the existing WWTPs. However, there is no related monitoring.

In addition, the lack of coordination among related parties has resulted in weak implementation of treated wastewater reuse by farmers. To address this issue, treated wastewater reuse can be implemented near the effluent discharge points of existing wastewater treatment plants, where it does not have any impact on relevant groundwater or surface water resources. The project is actively seeking to improve actual reuse and related infrastructure in areas where it is possible to increase reuse.

6. Make evidence-based decisions for water sector investments

The integration of Water Evaluation and Planning (WEAP) analysis and similar scenarios in the decision-making process is needed for resources management and investments planning. It is important that investment decisions rely on proper monitoring and analysis of water resources data, considering climate change impacts and the decline of conventional resource availability and exploitability in the water supply strategy and project planning. Data collection and analysis is essential, along with maintaining a quality database. Having these strong data will allow for the creation of more evidence-based policies. Data collection should cover a range of factors: long-term availability, exploitability, quality, protection, feasibility of raw water treatment, climate change impacts, actual uses, demand prognosis, costs of water, allocation planning, joint project and capital investment planning, and many other aspects.

Conclusions

Jordan is facing a complex challenge in managing its water resources given the country's population growth, climate change, and the dwindling availability of conventional water resources. Jordan's water scarcity is exacerbated by the ongoing Syrian refugee crisis, which has added pressure to the already limited water resources of the country. The

National Water Master Plan (NWMP-3) has been a significant milestone for Jordan, as it allowed for the identification of the demand gap for water supply at the municipal level, enabling future projections and predictions for water supply and demand.

However, the demand for water in Jordan is expected to rise significantly in the coming years, and the availability of conventional water resources is projected to decrease. Therefore, to address the existing supply gap, massive investments in desalination technology such as the Aqaba Amman Water Desalination and Conveyance (AAWDC) project are necessary. Moreover, Jordan needs to adopt a holistic approach to water resource management that includes policy interventions, efficient use of available water resources, and the incorporation of new technologies.

The successful implementation of policy interventions outlined in NWMP-3 is crucial to ensuring Jordan's economic resilience in the future. The government and stakeholders must work together to coordinate and share information, prioritize cost as the primary criterion for determining water source utilization in specific regions, and incentivize the use of treated wastewater for agriculture. This strategy will not only reduce the demand for conventional water resources but will also improve the economic viability of the agricultural sector.

In addition to these policy interventions, the development of a comprehensive water resources allocation plan and a water resources allocation committee is essential for effective policy implementation. It is crucial to incorporate water costs from different supply channels and plan for water reuse, especially for industrial and agricultural demand. Furthermore, creating incentive programs for farmers to use treated wastewater for irrigation and integrating evidence-based decision-making into water sector investments using tools like WEAP analysis and scenarios can help promote a resilient water system and foster economic sustainability in Jordan.

Overall, a sustainable and resilient water management system is critical for Jordan's economic and social development. Effective policy interventions, efficient water use, and the incorporation of new technologies are essential components of this system. By adopting a holistic approach to water resource management, Jordan can mitigate the impacts of water scarcity, ensure economic resilience, and provide sustainable access to water for its population.

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Secured Urban Water Supply for the City of Windhoek, Namibia

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Key Messages

- Water resilience is crucial for Namibia's economic resilience, particularly to ensure food security, as the country is highly vulnerable to water-related risks like droughts and floods.
- Closure of the industries in Namibia's capital of Windhoek due to water scarcity would create dramatic economic losses of about US$ 1.5 million per day on top of remarkable social consequences such as unemployment, poverty, and hunger.
- The Managed Aquifer Recharge (MAR) system in Windhoek has proven to be a cost-effective and dependable approach for augmenting water supply, meeting increasing demand, and mitigating the risks of water scarcity caused by droughts and climate change. MAR has increased crop yields by up to 50% in some areas of Namibia and enabled farmers to irrigate larger areas and diversify their crops, resulting in increased food security and income.
- In order to ensure the most effective use of resources, investment in water infrastructure must be tailored to meet the specific needs of the country. Conducting a cost-benefit analysis and pilot testing before

scaling investments are critical for success, as they enable the accurate measurement of results and performance, providing access to crucial insights.

Namibia's Economy and Water Risk

Climate resilience is a crucial factor in ensuring economic resilience, particularly in the case of Namibia, a middle-income country located in southern Africa. The country is highly vulnerable to the effects of climate change, and water is at the forefront of its climate resilience efforts. With a population of 2.5 million, Namibia faces the challenges of increasingly frequent and severe droughts and changes in precipitation patterns. These challenges significantly impact the availability of water, agriculture, tourism, and other sectors that are crucial to the country's development. It is, therefore, imperative to address these issues urgently to ensure Namibia's sustainable development from both economic and social perspectives.

In 2022, Namibia's GDP was approximately US$ 23 billion, which translates to a per capita GDP of around US$ 9,200 per year (World Economics, 2023). The Namibian economy is heavily reliant on natural resources, particularly minerals and fish, which account for the majority of the country's exports. The tourism, mining, and agricultural sectors are the main contributors to Namibia's GDP, accounting for approximately 15%, 10%, and 4%, respectively (International Trade Administration, 2023).

Namibia is one of the most water-scarce countries in the world and highly vulnerable to droughts which have led to significant food insecurity with severe social and economic consequences.

While agriculture plays a vital role in Namibia's economy, employing more than 50% of the labor force as compared to nearly 20% in tourism and only 3% in mining, the scarcity of water directly limits agricultural productivity, aggravating the issue of food and social insecurity (World Atlas, 2023).

Building economic resilience is imperative for Namibia, particularly in terms of ensuring food security, given the country's susceptibility to water-related risks such as droughts and floods. Namibia has been severely impacted by these challenges, As of October-November 2021, approximately 659,000 people, or a quarter of Namibia's population, faced crisis levels or higher of food insecurity, with 102,000 people in emergency conditions. This nationwide food insecurity was caused by a drought experienced in 2019, increased prices of food and non-food items between April-September 2021, and the impact of COVID-19 measures on supply chains and livelihoods (IPC, 2021).

It is important to recognize that water scarcity not only exacerbates food insecurity but also other social issues related to health, education, and gender equality. Women and girls, who are often the primary water collectors in rural areas, can be disproportionately affected by the time and effort required for water collection, limiting their access to education and economic opportunities (UNDP, 2022).

Namibia's water supply is greatly affected by the impacts of climate change on the country's limited freshwater resources and high variability in rainfall. The average annual rainfall in Namibia is currently only 350 mm, which has resulted in the country relying heavily on underground aquifers and the perennial river system for its water supply; however, these groundwater resources are facing significant pressure due to over-abstraction, climate change, and land-use practices.

The groundwater resources available in Namibia remain stagnant and are not expected to increase in availability. At the same time, there is an exponential increase in water demand in many economic sectors. This highlights the troubling pattern of rising water demand surpassing the supply in the country, despite the current installed capacity of water. Namibia's estimated total renewable freshwater resources are a meager 422.5 MCM per year, and at current rates of demand, they are projected to be overexploited in less than 10 years. This situation underscores the urgent need for Namibia to implement measures to manage its water resources sustainably and efficiently to avoid exacerbating the already critical water scarcity situation.

Managed Aquifer Recharge (MAR) as a Climate Adaptation Measure

Heavy rain and flood events as well as droughts threaten the livelihoods of the people either by a lack of water or by a surplus of water. In these situations, the storage of water in natural or built infrastructure is a key adaptation strategy. Aquifers are nature-based water reservoirs, whose functions can be artificially "enhanced" by MAR. MAR describes the intentional recharge of water to aquifers for subsequent recovery or environmental benefit. Thereby, it takes advantage of surplus water resources during flood periods through storage in the subsurface and its usage during dry seasons. In aquifers, water is well protected against pollution and evaporation, which is an important factor in arid and semi-arid environments and in comparison, with surface water reservoirs.

MAR could be very different technologies, based on infiltration, injection or dam structures. Aquifer Storage Recovery (ASR) and Aquifer Storage Transfer and Recovery (ASTR) are technologies which utilize injection wells to inject water into the aquifer. Other technologies, such as dune infiltration, infiltration ponds, percolation ponds, or rainwater harvesting, accumulate water on the surface and enhance the infiltration into the underground through longer retention times and an increased infiltration area. Other technologies require a greater effort including the construction of underground measures (e.g., underground dams or sand dams). These approaches create artificial underground water storages that have similar properties as natural aquifers. Rainwater, storm water runoff, river water, surface water, or even treated wastewater work well for MAR purposes. Depending on the water quality and on the recharge technology, additional water treatment processes are required before the water recharges the aquifer.

This innovative technology allows the usage of the underground storage capacities as a water bank, where water can be deposited when available and withdrawn when required. Thereby, MAR secures water supply, contributes to climate adaptation, and dramatically increases drought resilience. Further, enhanced water availability allows for more agricultural irrigation and thus increases agricultural yield, which supports food sovereignty and socioeconomic development. Another advantage is the reduced surface run-off that reduces the risks of flood events and erosion.

MAR in Windhoek

Windhoek is the capital city of Namibia and serves as the economic, political, and cultural hub of the country. Windhoek is the center of economic activities in Namibia and hosts the main share of the country's manufacturing activities, business and financial services (Mapani et al., 2023). According to the Namibian Statistics Agency's Quarterly Gross Domestic Product (GDP) report for the third quarter of 2021, the city of Windhoek contributed 21.6% to Namibia's GDP in that quarter. The services sector is the largest contributor to the city's GDP, accounting for 54% of the total, followed by trade and manufacturing sectors in 2022.

Aside from the challenges posed by climate change, increasing economic development and population growth in Windhoek puts further stress on the water supply. Murray et al. (2018) expects more than a doubling of the population from around 326,000 in 2018 to around 790,000 in 2050. While water supply in 2018 was around 27 MCM/year, in 2050 the demand is estimated to be around 50 MCM/a (Murray et al. 2018). These numbers indicate that a population increase of about 242% will be accompanied by a water demand increase of about 185% which implies a reduction of the per capita demand of around 24% from 83 MCM/year to 63 MCM/year. The closure of industries of Windhoek due to non-availability of water would bring dramatic economic losses of about US$ 1.5 million per day (Zheng et al. 2021). This could lead to huge social consequences such as unemployment, poverty, and hunger.

Due to these aggravated climate circumstances, the city of Windhoek already considered MAR in 1997 as an alternative to piping water from the distant Okavango River. First assessments and injection tests started subsequently. In 2004 NamWater, a public water utility in Namibia, conducted a study to investigate the feasibility of the MAR project including a cost-benefit analysis and a comparison with other alternatives as the construction of pipelines from the perennial surface water resources and the utilization of the far distant Tsumeb and Karst III Aquifers for emergency supply. Both alternatives are more expensive than the MAR approach. The water supply costs for the Tsumeb and Karst III Aquifer was estimated to be US$ 4.3/m^3 and for the Okavango pipeline US$ 35.6/m^3. The costs for the MAR scheme are US$ 2.0/m^3 (Tuinhof et al., 2012). Since the MAR scheme turned out to be the most cost-efficient option, injection started in 2006 with six injection wells. To serve the increasing demand and to secure water supply, twenty further wells were constructed in 2011 and twelve additional wells in 2016 (Murray et al., 2018).

The major share of the water supply for the city of Windhoek is stemming from three dam systems (Omatako Dam, Swakoppoort Dam, and Von Bach Dam) that store and accumulate surface water during the rainy season when the rivers are carrying water. The water is then purified and distributed into the supply systems. Surplus water that is not required for the direct supply of the city is injected into the Quartzite Aquifer after its purification. Additionally, a water treatment plant purifies wastewater up to drinking water standards and enables its injection and usage. The aquifer conditions and its overlying geological layers protect the stored water against pollution and evaporation, which is a big advantage in comparison to a long-term storage with dams. In times when no surface water is available, extraction wells pump the water out of the aquifer and distribute it into the water supply system to serve the populations as well as the industry and agricultural needs

(Tuinhof et al., 2012). This scheme consists of pumps, pipelines, treatment systems, and wells. The operation from 2006 to 2013 directly contributed to an increase of the water level and thus allowed higher sustainable abstraction rates.

The aquifer infrastructure is currently owned and operated by the City of Windhoek, while the water supply infrastructure is owned and operated by NamWater. To establish, manage, and operate a MAR scheme, knowledge and expertise is required and needs to be addressed to ensure an optimized, long-term utilization of the available resources and infrastructure.

MAR Solution Saves Namibia Amidst Aggressive Droughts by Serving as a Supply Backstop

From 2014 onward, Namibia has experienced a dry period with a reduction in precipitation rates, which also reduced the surface water availability. Thus, the recharge into the aquifer was intermittent and the groundwater levels dropped by around 40 meters because of the groundwater extraction. Without the recharge from 2006 to 2013, the abstractions would not have been possible at these numbers and the groundwater would now be at even lower levels. However, this shows that the scheme requires input, which is dependent on climatic conditions. If these conditions are not suitable for groundwater recharge (e.g., lack of precipitation and surface water availability), then the MAR scheme has to pause its operation until the conditions enable it. Thus, although the scheme improves drought resilience for the case of Windhoek, it should not be relied upon solely.

The MAR scheme of Windhoek functions as supply backstop, which ensures that the city is able to overcome prolonged drought periods that include a failure of surface water reservoirs. During rainy seasons, only 4% of the water supply comes from the aquifer and the main water source is surface water, which contributes around 76% to the water supply. This huge amount requires substitution during drought periods when no surface water is available.

Economic Potential

The MAR scheme lowers this risk of aquifer depletion significantly, further securing and improving the water supply situation. This allows the sustainable utilization of additional water resources and offers even further economic potential. For example, additional water for agricultural irrigation increases the agricultural yield and generates more jobs and higher incomes. The scheme also reduces the need to import expensive water from remote sources in the North. According to a study conducted by the International Water Management Institute (IWMI), MAR has increased crop yields by up to 50% in some areas of Namibia. In addition, MAR has enabled farmers to irrigate larger areas and diversify their crops, resulting in increased food security and income (Bekchanov et al., 2016).

MAR as a Reliable and Cost-efficient Option

MAR has proven to be a reliable and cost-efficient water augmentation option to serve the rising demand and to avert the threat of water scarcity reinforced by droughts and climate change. The scheme is cost-effective due to its ability to utilize existing infrastructure and the fact that the water treatment process is less energy-intensive than other conventional treatment methods. This facility — the water bank of the city of Windhoek — under the current dimensions is expected to be able to provide security for three years as the sole water resource during drought conditions (Murray et al., 2018). According to Murray et al. (2021), expanding the water bank storage to 61–71 MCM would allow for the extraction of approximately 19 MCM of water per year, further enhancing the capacity of the MAR scheme to meet the increasing water demand and provide a reliable and sustainable water source for Windhoek.

Diversifying Water Investment Infrastructure

The Windhoek MAR scheme's integration with alternative water supply options can offer a significant economic opportunity for investors. For instance, the integration of the MAR scheme with desalination can yield an economic internal rate of return (IRR) of approximately 94%, while the integration with the Okavango River transfer scheme can yield an IRR of around 68% (Murray et al., 2021). These IRR values significantly exceed the economic opportunity cost of capital of 10% and offer attractive investment options for investors. Moreover, this integration can provide improved water security and reliability for Windhoek, with desalination being capable of producing up to 26 MCM of water per year, as per the Windhoek Municipality's estimates. Therefore, the Windhoek MAR scheme's integration with alternative water supply options offers an excellent opportunity for investors to realize attractive returns while contributing to the city's water security and resilience.

Positive Net Present Value of the Project

To allow for future operation of the scheme, it is expected that the beneficiaries shall co-finance the operation over the economic lifespan of the project with US$ 115 million for operational costs and capital replacement over 30 years. This can be done via water expenses, which can be adopted according to the amount and usage. Despite a conservative set of assumptions, the project still yields a positive net present value, regardless of the choice of the water supply augmentation scheme in the future — whether it is desalination and transfer, or transfer from the Okavango River.

Conclusion and Way Forward

Namibia is grappling with a growing water scarcity issue due to severe changes in precipitation patterns and an arid climate — a condition only expected to worsen with climate change, making the country more susceptible to droughts. This poses significant challenges to the limited water supply, which will be exacerbated by the increasing water demand from population growth. Therefore, water resilience policies and programs are essential to withstand economic shocks and maintain socioeconomic well-being, given the country's vulnerability to water-related risks like droughts and floods. While agriculture plays a vital role in Namibia's economy employing more than 50% of the labor force, the scarcity of water directly limits agricultural productivity, aggravating the issue of food and social insecurity (World Atlas, 2023).

Windhoek is the center of economic activities in Namibia and hosts the main share of the country's manufacturing activities, businesses, and financial services (Mapani et al., 2023). Besides the climatic situation, the increasing economic development and population growth of Windhoek put further stress on the water supply. Murray et al. (2018) expect more than a doubling of the population from 2018 to 2050, which will be accompanied by a water demand increase of about 185%. The relationship between water resilience and economic resilience in the case of Windhoek is a direct relationship. The closure of the industry of Windhoek due to non-availability of water would bring dramatic economic losses of about 1.5 million USD/day (Murray et al., 2021). This leads to huge social consequences such as unemployment, poverty, and hunger.

The MAR scheme in Windhoek has demonstrated itself to be a reliable and cost-efficient water augmentation option to serve the rising demand and to avert the threat of water scarcity being exacerbated by droughts and climate change. The scheme has increased drought resilience and further secured and improved the water supply situation, allowing the sustainable utilization of additional water resources and offering economic potential. Conducting a cost-benefit analysis and pilot testing before scaling proved to be a critical success factor for the process. It enabled the accurate measurement of results and performance, providing access to crucial insights. Nevertheless, a MAR scheme is limited by the storage capacity of the aquifer and its requirement for water recharge, despite its effectiveness in buffering prolonged drought periods.

Windhoek aims to further diversify its water resources and promote integrated resource management to ensure a sustainable water supply for the future. This can take place by combining technological approaches and water management strategies. Along with the MAR scheme, which has already demonstrated reliability and cost-effectiveness, enhancing the water treatment plant's treatment and injection capacities could enhance the city's water supply. Further, Windhoek has integrated water-saving measures and rooftop rainwater harvesting technology, while also exploring options such as expanding the aquifer's storage capacity and increasing the water injection rates for aquifer recharge. Mapani et al. (2023) suggest drilling more deep wells to expand the storage capacity of the MAR scheme, and verifying if the water treatment plant can handle an increased capacity beyond its current 40% grey water recycling rate.

The drought index strategy is one of the implemented water-saving measures, targeting a 35% reduction in water usage. For the water scarcity and drought programs to be successful in Namibia, they should be staged for severity and intensity. Programs should also identify protected groups, ecosystems, and sectors and be revised regularly to incentivize adjustment to evolving extreme events.

Economic resilience requires active participation from both the public and private sectors. It is essential for the public sector and significant public finance, investment, and regulatory bodies to articulate a clear vision of the goals and strategies for economic resilience. Thus, integrated water planning and coordination across all sectors is vital for navigating these challenges. Overall, a comprehensive and urgent approach is necessary to address the challenges of increasing water demand and varying water availability resulting from expected climate changes.

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Managing Afghanistan's Water Crisis for Economic Resilience

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Key Messages

- Afghanistan, a country with high political instability, suffers a huge water shortage problem owing to ongoing conflict, poor institutional management, and climate change.
- Climate change is worsening the already severe water scarcity issues in highly populated urban areas like Kabul, Kandahar, and Hirat.
- Water resilience is crucial for Afghanistan's economic resilience, but the country's water sector still faces challenges such as financial limitations, lack of data, poor coordination, and security issues.
- Over the last 20 years, the role of ODA financing in the water sector was remarkable, with Afghanistan receiving over US$ 4 billion in ODA to improve access to safe drinking water, increase irrigation capacity, and enhance water management and governance. However, according to the OECD, Afghanistan needs to invest more than 6% of its GDP to accommodate flood risks.
- The investment gaps are significant, and the recent Taliban takeover has exacerbated the humanitarian crisis in the country.
- Reaching economic resilience via water resilience in Afghanistan (under the de facto authorities) is solely possible through the

international community. This would require a coordinated and comprehensive approach that addresses the root causes of water insecurity and economic fragility in the country.

- Establishing the Afghanistan Water and Climate Emergency Fund under the UN Special Trust Fund for Afghanistan (STFA), investing in the building and rehabilitation of water infrastructure, and improving public awareness to promote water conservation are recommended pathways until there is a possible handover to a legitimate government.

Introduction

This paper discusses Afghanistan's water resources, changes in the sector before the Taliban takeover, and the pathways to economic resilience via water resilience in the current situation, where the de facto authority is leading the country without any international community recognition. The paper draws a map of recent advances in the water sector, current challenges, and the way forward by recommending the establishment of an Afghanistan Water and Climate Emergency Fund and creating the Afghanistan Water and Climate Emergency Working Group.

Background

Years of political instability and conflict severely affected Afghanistan's economy, resulting in poverty and highly underdeveloped water resources. The COVID-19 pandemic and the Taliban takeover in August 2021 undermined the development gains of the past 20 years and exacerbated conditions further — inducing economic contraction and aggravating food insecurity. According to the World Bank (2022), the GDP has contracted by 20.7% in 2021.

The agriculture sector contributes 25% to Afghanistan's GDP, employs 40% of its labor force, and consumes more than 90% of the water, yet cannot provide enough food for Afghanistan's population. Presently 20 million Afghans are acutely food insecure, and more than 6 million are in close to famine-like conditions. Even though 90% of household incomes are spent on food, Afghanistan is ranked the highest worldwide for insufficient food consumption rate. Nine of ten households consumed inadequate food, with no changes in the last 12 months (WFP, 2023).

Despite all the rehabilitation efforts and the engagement with the international community for two decades, Afghanistan still has a huge water shortage problem owing to ongoing conflict, mismanagement, poor institutional and human capacity, and climate change. The country has a minimal capacity for water storage of 140 m^3 per capita per year — the lowest in the world. In 2010 the water production per capita in Kabul city was approximately 16 liters per person per day (World Bank, 2010) and has since been unfortunately declining; it is one of the lowest water production figures for any city in the world. For context, that same year water production per capita was 240 liters per person in Dehli, India and 500 for Los Angeles, USA.

Afghanistan, despite having significant water resources, is unable to utilize them effectively. The country's rivers, including the Amu Darya, Helmand, Harirud, and Kabul, offer potential for hydroelectric power generation, irrigation, and other uses. However, due to decades of war and conflict, the existing water infrastructure is severely damaged and inadequate. Moreover, many streams and rivers in Afghanistan flow into desert regions, where they evaporate without replenishing the major river networks. Other rivers and streams only flow seasonally, exacerbating water scarcity and limiting their potential use for agriculture and other purposes.

Groundwater resources are also under immense stress — demand often exceeds supply. In rural Afghanistan, groundwater is largely used for irrigation through Kareezes, mountain springs, and solar-powered wells. As of the end of 2021, three provinces had experienced a drying up of over half (53%) of their water points. (UNICEF, 2022). The water scarcity crisis has also had a severe impact on aquifers in the central region, causing reduced water levels and the drying up of various sources such as hand-dug wells, springs, kariz, boreholes, and streams.

Technological innovation in the form of solar-powered deep wells made it possible, especially in southwestern Afghanistan, to change hundreds of thousands of hectares of the desert area into agriculturally productive land, much of it cultivated with opium poppy (Mansfield, 2020). Water tables are also dropping rapidly in metropolitan areas due to over-abstraction for domestic use (USAID, 2021). Groundwater serves as the backup water source during times of surface water scarcity. The loss of these aquifers (or the fossil waters) will be irrecoverable for Afghanistan. All this is happening in a state where very little is known about these aquifers — including how they are recharged and when they might run dry.

Water-related Climate Risks

Climate change exacerbates water sector problems, such as glacial melt, drought, shifting precipitation patterns, and increasing temperatures (Hanasz, 2011). Based on Afghanistan's National Environmental Protection Agency (NEPA) report, temperatures in Afghanistan rose by 1.8 °C between 1950 and 2010, or twice the global average. Afghanistan is one of the most climate-vulnerable countries in the world due to its geography, sensitivity to changing weather patterns, and low coping capacity to deal with climate change (Hakimi and Brown, 2022). In the Global Climate Risk Index 2021, Afghanistan was the sixth most affected country in 2019, with total losses of US$ 548.73 million (Eckstein et al., 2021).

The impact of climate change has caused a decrease in precipitation, which has further aggravated the already strained water resources due to population growth. This has resulted in a severe water scarcity situation in densely populated cities such as Kabul, Kandahar, and Hirat, where 66% of the country's urban population resides. Groundwater levels have been declining across Afghanistan, with Kabul witnessing a significant drop from eight meters below land in 2003 to 45 meters in 2021. Moreover, in the first eight months of 2021, over 29,000 people in 13 provinces were affected by natural calamities such as floods, which have added to the problems faced by the people.

The Hindu Kush Mountains in the country are natural storage facilities and sources of freshwater. They accumulate snow during winter and snowmelt and rainfall during spring. These are released as freshwater alongside frozen water from glaciers in the summer, which sustains the vital flow of rivers. This balance of the rivers' systems is being altered, and the people who benefit from these rivers face severe consequences. In Afghanistan, increasing temperatures cause more precipitation in the form of rain instead of snow, resulting in shrinking glaciers and more water when it is not needed. Unfortunately, in the past half-century, larger glaciers in the Pamir and Hindu Kush Mountains have shrunk by over 30%, and small glaciers have disappeared completely (UNEP, 2008). These impacts will likely intensify in the coming decades, posing significant challenges to water availability and quality in Afghanistan.

Transboundary Issues

Iran considers the development of agriculture and dams in the upstream area of the Helmand Basin as a significant threat to the environment and water resources, leading to an increase in tension due to water scarcity and environmental degradation. The Helmand River, which contributes 70% of the total inflow to the Hamun Lakes and is crucial for farmers in Afghanistan and Iran, has seen reduced downstream flow, leading to the desiccation of the lakes (Akbari and Haghighi, 2022). The desiccation of the lakes has significant environmental and economic impacts on the surrounding population and ecosystem, including air pollution and concerns about water scarcity and environmental degradation. Given that the majority of available water in Afghanistan and Iran is consumed for irrigation, it is essential to address the decreasing inflow of water to the Hamun Lakes.

Water Management Prior to the Taliban, 2021

As one of the vital sectors for Afghanistan, water resources were given priority during the 20 years prior to the Taliban (only after the security organizations). The changes and enhancements in the water sector can be broadly categorized into two main areas: 1) strengthening good water governance and 2) infrastructure development.

Good water governance is essential to achieve water security and provide water services. In order to be able to respond to community needs and deliver services, the Ministry of Energy and Water (MEW) amended the Afghanistan Water Law of 2009, developed 35 legal documents (i.e., regulations), policies and strategies, and implemented institutional changes at the ministry as well as at the river basin level. The government and international community, via different platforms (e.g., training, workshops, and graduate scholarships abroad) trained a large number of water resources engineers and specialists who were able (to some extent) to fill the human capacity gap in managing water resources.

The previous administration's budgetary constraints and limited spending power were one of the major obstacles in dealing with water resources and climate change. Between 2013 and 2015, the government spent over US$ 100 million annually on climate change through its development budget; nevertheless, this amount was insufficient compared to the US$ 662 million needed per year (Islamic Republic of Afghanistan, 2015)

Related to infrastructure development, a large amount of focus and resources were given to building or rehabilitating large and medium-scale dams in Afghanistan (e.g., the Salma Dam, Kamal Khan Dam, Kajaki Dam Second Phase, Bakhshabad Dam, Dahla Dam, Shorabak Dam, Pashdan Dam, Shah-o-Aros Dam, Tori Dam, Shahtoot Dam, Machalgho Dam, Sultan Dam, and Palato Dam). Some of these dams were completed, and the remaining were under construction. Additionally, 47 more dams were surveyed, designed, and either contracted for construction or under the procurement process. In addition to these large and medium-scale dams, a program of around 4,500 check dams was also under implementation.

There were also irrigation projects of different scales, ranging from the Shahi Canal (serving 22,000 hectares of irrigable land) up to the Khoshtepa Canal in Northern Afghanistan (serving 500,000 hectares of irrigable land). Further, hundreds of main canals were engineered, and around 3,000 irrigation schemes were rehabilitated.

The previous administration worked with the international community to install 183 hydrometeorological and hydrogeological stations for data collection. Four early warning system pilot stations were set up to lessen the negative consequences of hydrometeorological risks on vulnerable communities.

Afghanistan's economic resilience is directly tied to water resilience. With all the advances, Afghanistan's water sector still needs more systematic efforts to utilize its water resources. Previous shortcomings were not only because of mismanagement and climate change; the water sector also struggled with financial limitations, data unavailability, and the involvement of many stakeholder ministries/agencies with very poor coordination. Above all, security was a massive problem for the water management projects. According to former Water Minister Mr. Takal, "Only in Machalgho Dam we had more than 130 security guards martyred, and hundreds wounded." This was done by the Taliban to obstruct government operations. More importantly, the security issue was from the neighboring countries because of the transboundary nature of Afghanistan's water.

Role of Official Development Assistance Financing in Water Infrastructure Development

The advances made in the last two decades were only possible with Official Development Assistance (ODA) for the water sector from various international organizations and donor countries. The water sector in Afghanistan is vital for its economic and social development, and ODA played an integral role in addressing water challenges. The key contributors that have provided ODA for the water sector in Afghanistan are the World Bank, Asian Development Bank (ADB), European Union, United States Agency for International Development (USAID), and UN agencies, particularly United Nations Development Programme (UNDP).

The assistance provided by these institutions was used for several purposes, such as the development of water infrastructure, rehabilitation of existing systems, and improving water governance and capacity building. These projects included the construction and rehabilitation of irrigation systems, on-farm water management, installation of water supply networks, rehabilitation of hydropower plants, and support for water resource management programs.

The ODA for the water sector in Afghanistan over the last 20 years has been notable; however, the water sector still needs a lot more. According to the World Bank, as of 2021, the total amount of funds allocated to the water sector in Afghanistan since 2002 was over US$ 4 billion. These funds have been used to support various programs aimed at improving access to safe drinking water, increasing irrigation capacity, and enhancing water management and governance in the country.

According to the OECD (2021), Afghanistan needs to invest nearly 3% of its GDP (around US$ 1 billion) in its water supply and sanitation infrastructure to achieve universal access to safely managed water supply and sanitation services. Not only are the investment gaps enormous compared to what is available in the country to invest in the water sector, but the Taliban takeover has led to a humanitarian crisis with millions of people in need of necessities such as food, water, and healthcare. In the meantime, to accommodate for flood risks, Afghanistan needs to invest more than 6% of its GDP in a business-as-usual scenario.

What is Next? Water Resilience towards Economic Resilience Mainstreamed by the International Community

Afghanistan's water resources are under enormous stress from the impacts of climate change, population growth, mismanagement of the sector in the last four decades because of continuous conflict and insecurity, financial limitations, insufficient technical capacity, data unavailability, and other drivers. Currently, Afghanistan is in a highly vulnerable situation confronting the second drought in four years — the worst of its kind in 27 years. The country has the highest number of people in emergency food insecurity worldwide (UNDP, 2022).

The following section will discuss the pathways to economic resilience via water resilience in the current situation of Afghanistan under the Taliban. Knowing that the international community has not yet recognized the de facto authorities in Afghanistan, working with them is not an option; therefore, this paper's recommendations rely on the current international organizations operating in Afghanistan, such as the UN agencies, World Bank, ADB, and some national and international NGOs.

Here are a few reassuring signs that could allow Afghanistan to take the first steps toward water resilience. First, the de facto authorities and the international community do not have political, religious, or cultural disagreements regarding addressing the current water and climate crisis. Secondly, international NGOs and United Nations offices are actively operating in the country. Examples include UNDP, UN-FAO, WFP, and others.

Reaching economic resilience via water resilience in Afghanistan (under the de facto authorities) is solely possible through the international community. This would require a coordinated and comprehensive approach that addresses the root causes of water insecurity and economic fragility in the country. All partners should work together, including bilateral donors who are already providing humanitarian aid (such as the World Bank, ADB, USAID, DFID, etc.), multilateral donors such as the climate finance institutions (e.g., GEF, GCF, and AF), and partners physically present in Afghanistan like the United Nations Offices (especially UNDP who has a wealth of experience in water resources and climate change projects), national and international NGOs, and local communities (e.g., Community Development Councils). All the major players must step up and participate in addressing the current water and climate problems. This paper recommends that a few key organizations, especially those in Afghanistan, including UNDP, UN-FAO, and the World Bank, establish the Afghanistan Water and Climate Emergency Working Group.

A good financial setup is of utmost importance in managing water resources and climate change. Thus, establishing the Afghanistan Water and Climate Emergency Fund is one way to give proper attention to climate change and water resources projects. Establishing the Fund will centralize and ring-fence the finance within a dedicated setup, allowing for coherent investment and improving the confidence of bilateral and multilateral donors. Furthermore, it will avoid fragmentation and promote collaborative planning, coordination, and prioritization of water resources and climate change. It is worth mentioning that the former government approved the formation of a national environmental and climate change fund with NEPA being the leading agency working on its establishment. Back then, the idea was also to give the right platform for financing the climate change agenda through grants (i.e., bi- and multilateral donors such as the GCF, GEF, AF, WB, ADB, EU, and others) and private investments.

Because of the political limitations with the de facto authorities, the faster path could be establishing the Afghanistan Water and Climate Emergency Fund as a separate wing under the Special Trust Fund for Afghanistan (STFA) by the United Nations. Established in 2021, the STFA is an inter-agency structure and UN-Multi-Partner trust fund to assist UN joint programming in providing basic human needs in Afghanistan. In its mandate, STFA has already been investing in climate change projects under the "Protecting Farm-Based Livelihood from Natural Disaster" pillar of the ABADEI Project; however, as stated before, in order to give the proper focus and attention to the water and climate crisis in Afghanistan, a separate, dedicated financial setup is necessary.

To first get Afghanistan out of this emergency and then reach economic resilience in the medium and long term(s), enhancing water resilience is a crucial factor. Here are some possible actions that could be pursued to enhance economic resilience via water resilience under the de facto authorities:

1. **Create the Afghanistan Water and Climate Emergency Working Group**, comprising key partners such as the UNDP, UN-FAO, World Bank, and others currently operating in Afghanistan. Moreover, establish the **Afghanistan Water and Climate Emergency Fund** under the UN Special Trust Fund for Afghanistan (STFA). This will centralize and ring-fence the finance within a dedicated setup, giving proper focus and attention to the country's water and climate change emergency and optimistically resulting in attracting funds from bilateral as well as multilateral donors.
2. With the current situation in mind, **provide humanitarian assistance**. Currently, in Afghanistan humanitarian assistance is critical for meeting the basic needs of vulnerable populations, such as food, water, and health. The international community could provide humanitarian assistance to address the immediate water and economic needs of Afghan communities, particularly those affected by conflict, displacement, and natural disasters like recent floods and droughts.
3. **Promote local ownership and participation**. Water resilience and economic resilience are best achieved when local communities and stakeholders are engaged and empowered to co-create and co-implement solutions that address their specific needs and priorities. The international partners could prioritize community-led water management and governance approaches, such as participatory water management committees, and support their capacity-building and resource mobilization

efforts. Furthermore, the working group could invest in institutional development and enhancing human resources capacity, as most water experts/specialists have been fired by the de facto authorities or left the country because of insecurities.

4. Through the setups mentioned above (i.e., the Working Group and the Fund), partners should **invest in the building and rehabilitation of water infrastructure**, such as check dams, irrigation systems, and wells, to increase water availability for domestic, agriculture, and industrial use. This will also reduce the impact of climate change, improve access to safe drinking water and sanitation facilities, increase agriculture productivity, and improve food security. Afghanistan's water infrastructure needs rehabilitation and expansion to meet the growing water demand and enhance water security. Rehabilitated irrigation systems have proven to help farmers by avoiding water shortages and allowing them to switch from low-earning to high-earning crops and generate higher revenues.
5. **Improve public awareness and promote water conservation and efficiency** to avoid over-exploitation of water resources, particularly groundwater. Water conservation and efficiency measures can help to reduce water demand and increase productivity, particularly in water-stressed areas. Long-term investments can be made in water-saving technologies like drip and sprinkler irrigation, rainwater harvesting, and water reuse to improve water use efficiency and reduce the stress on water resources.
6. **Once a legitimate government is in place, hand over** the Afghanistan Water and Climate Emergency Fund and the Emergency Working Group to the Ministry of Energy and Water (MEW), the National Environmental Protection Agency (NEPA), and the Ministry of Finance (MoF).

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South Africa: The Resilient Transition

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Key Messages

- South Africa is a water-scarce country, and climate projections show a worsening trend due to rising temperatures and shifting rainfall patterns in the future. The country faces an acute water scarcity challenge, especially in the Western Cape province.
- Despite its scarcity, water is poorly managed. Water loss costs municipalities about R10 billion each year. Moreover, 40% of the country's wastewater is untreated, and a significantly low proportion is reused.
- To address the country's water challenges, the government has adopted new practices for better water resources management, improved water supply and sanitation services, and alignment of SA's water policies and strategies with climate change impacts. These include reforms in policy, investment, and demand management.
- The most important costs for adaptation measures will be in building a resilient water system, followed by resilient cities and transport. Financing requirements in the water sector will be higher between 2022 and 2030 than in the

next decades given the urgency to address SA's water challenges up front.

- Given the "public goods" nature of the necessary investments, there is a need to improve public investment management and increase coordination across different tiers of government.

Introduction

South Africans are increasingly exposed to climate-related risks. In 2021, the country declared its third national state of disaster for drought in the last four years, and Durban was devastated by major floods in 2020 and April 2022. These climate risks are projected to worsen in the future. Several key economic sectors are particularly vulnerable to climate shocks, including agriculture, infrastructure, and tourism (especially nature-based tourism), as are several cities. Climate risks disproportionately affect poor people, who live in locations prone to disasters, have more fragile assets, do not have the resources to adjust their lives to changing climate conditions, and are underrepresented in decision-making processes.

Building a resilient economy will require significant investments in the water, road, and agriculture sectors as well as in cities. The Country Climate and Development Report (CCDR) estimates that these investments will amount to about 1.3% of South Africa's (SA's) GDP per year or R2.4 trillion in net present value between 2022 and 2050. The necessary investments need to be implemented early to lower the country's vulnerability. To reduce these costs, the government could adopt structural reforms to improve the efficiency of public spending and incentivize private sector investments in green and climate-smart projects.

Resilient Water: Vulnerabilities and Adaptation Measures

SA is a water-scarce country, and climate projections show a worsening trend due to rising temperatures and shifting rainfall patterns in the future. With mean annual precipitation of just 450 mm and over 98% of its freshwater resources already allocated for different uses, the country faces an acute water scarcity challenge, especially in the Western Cape province. The water scarcity index is expected to increase under all future climate scenarios, with the largest negative impacts in the Orange, Limpopo, Vaal, Berg, and Olifants Rivers.

The reliability of bulk water supply is no longer assured for main urban centers. Key cities and towns such as Johannesburg, Cape Town, Randburg, and Pretoria are all in areas of projected high-water scarcity. The economic costs and negative implications for living conditions, especially for vulnerable groups, can be significant for the country. Another source of vulnerability is the country's heavy dependence on water transfers from Lesotho.

Despite its scarcity, water is poorly managed. Agriculture accounts for the largest share of water use (57%), followed by industry (around 21%) and municipalities (21%). On average, SA loses about 35% of its municipal water (against a global best practice of about 15%) and about 24% of its water allocated to irrigation. This water loss costs municipalities about R10 billion each year (World Bank, 2019). Moreover, 40% of the country's wastewater is untreated, and a significantly low proportion is reused. More than half of all wetlands have been lost over the past decades, and one-third of the remaining ones are in poor condition (DEFF, 2021).

Although SA is a water-scarce country, some areas are prone to flood risk. This is projected to intensify in future, especially in the southern and eastern parts of the country. In 2021, all nine provinces were adversely affected by flooding. And in 2022, the storms and flooding in KwaZulu-Natal killed over 450 people, destroyed properties, caused a crisis of water supply and sanitation provision (and associated impacts on public health), and disrupted commerce due to impacts on Durban's port and highways/ railways linking the port to the rest of the country. The damages were estimated at over R17 billion or 0.3% of GDP.

Investments and Policy Reforms Required for a Climate-resilient Water Sector

To address the country's water challenges, the government has adopted several policies and strategies that call for better water resources management, improved water supply and sanitation services, and alignment of SA's water policies and strategies with climate change impacts. These policies and strategies recommend a series of interventions that will support adaptation, including:

- Policy and regulatory reforms: Various strategies have proposed monitoring climate-related data, sharing this data across several tiers of government and non-governmental organizations and citizens, and processing and using this data to guide planning and decision-making, including early warning systems and the development of comprehensive plans to respond to disasters. The importance of coordinated implementation of these policies and strategies has also been emphasized.
- Investments in supply augmentation: To address the projected water demand gap, augmentation measures include harvesting water, importing additional bulk water from outside SA, increasing groundwater use, and introducing unconventional water supply options such as treated wastewater reuse and desalination.
- Demand management measures such as conserving water, importing water-intensive goods, and recovering water from acid mines are also needed.

Transitioning from coal to cleaner energy sources can help augment water availability, resulting in both climate and development benefits. About 7% of SA's total water use is to cool down coal-fired power plants and wash coal, so the decommissioning of these plants and the closing of coal mines will result in additional available water. This "saved" water could be allocated to different economic sectors according to the social and environmental benefits they generate for society.

The private sector has a limited role in SA's water space. While the private sector is active in major bulk water supply schemes, its role in municipal water supply services is limited in comparison with other middle-income countries. Efforts are underway to improve the enabling environment for public-private partnerships (PPPs) in the broader water supply and sanitation value chain, but implementation remains slow.

Adapting to climate change and building water resilience will be costly but will bring significant benefits. The proposed actions under the National

Water and Sanitation Master Plan require incremental investments of about 0.4% of GDP per year, or a cumulative cost of R720 billion in net present value over the period 2022–2050. This figure is in line with the projected costs for the country to meet Sustainable Development Goal 6 (sustainable access to water supply and sanitation), demonstrating the inextricable link between climate resilience and good development outcomes (DWS, 2023).

Recommendations

- Reduce both technical and financial losses in the system. This starts with fixing dilapidated pipe networks and improving municipal water supply governance, which requires improvements in coordinated planning by the national, provincial, and municipal authorities and strong links with the sectoral strategies for agriculture and urban development. On the supply side, existing plans should account for future climate change impacts on the availability of water resources and changes in water demand.
- Manage water demand through pricing strategies. The government could consider forms of water pricing that incentivize more efficient use in agriculture and contribute to more assured municipal supplies. For example, linking water pricing to increased investments in irrigation and other infrastructure could lead to an improved allocation of resources.
- Close the water service gap and reduce flood risks in poor urban and rural areas, which are vulnerable to water scarcity and extreme weather events. Over three million people still do not have access to a basic water supply service and 14.1 million people do not have access to safe sanitation. Poor households are disproportionately vulnerable to flood risks. Interventions should include mapping and characterizing communities and locations vulnerable to projected shifts in water demand and floods and improving infrastructure in these vulnerable locations through land-use planning, development controls, consideration of climate risk in designs, and use of green infrastructure, including nature-based solutions (NBS).
- Strengthen links between the energy transition and water use. Transitioning away from coal will free up water resources for other activities. The government could plan in advance how to optimize this by assessing the volume of water that can be reallocated, the mechanisms to reallocate it to main users, the investment costs, and the timeline.
- Develop innovative financing solutions for water-resilient projects, including through PPP initiatives. The private sector can complement the government's role in the water sector. However, the enabling environment needs to be improved to promote

Resilient Agriculture: Vulnerabilities and Adaptation Measures

Although agriculture only accounted for 2.9% and about 5% of SA's GDP and employment in 2021, this sector has a central role to play in poverty eradication and inclusive development. Rural areas report a higher poverty rate than urban centers, and a resilient agriculture has significant implications for the country's food security and exports. There are significant opportunities for expansion and diversification of agricultural activities, including in the Eastern Cape, Limpopo, and KwaZulu-Natal provinces, which are home to a large proportion of smallholder farmers, who are among the poorest in the country.

Agriculture is vulnerable to climate change. The combination of higher temperatures, seasonal variations, and lower precipitation has led to water scarcity, land degradation, and greater exposure to pests. Smallholder agriculture, which is predominantly rainfed, is particularly vulnerable to climatic shocks and natural disasters. A 2019 report by the South African Insurance Association indicates that 42% of farmers incur losses resulting from droughts, followed by 29% from storms and 28% from floods (SAIA, 2019). Smallholder agricultural development is hampered by large unmitigated climate risks. As a result, yields have been negatively affected and could decrease by 25% in the most vulnerable regions. The demand for irrigation is also projected to increase by 15–30% under the extreme climate scenario (SSP3, dry) over the next decades.

SA's long coastline and rich marine biodiversity provide opportunities for expanding fisheries and aquaculture, but are also exposed to climate change. SA's fisheries sector accounts for only 0.1% of the country's GDP but the commercial sector employs over 27,000 people directly and an estimated 81,000 to 100,000 people indirectly, while the subsistence sector employs 30,000 fishers. Most fishing activity takes place along the western and southern coasts. Climate change affects SA's fisheries and aquaculture sectors differently. Marine fishery stocks are already dwindling due to overfishing, but a changing climate exacerbates these pressures. Climate change impacts on fisheries include changes in the spatial distribution of species and lower abundance and productivity of marine resources. This makes fisheries management less effective. Overall, fisheries production is projected to decline by 13.3% by 2030. In contrast, the aquaculture sector is moderately vulnerable to climate change and is projected to grow at 61.8% per year over the next decade.

Investments and Policy Reforms Required for a Climate-resilient Agricultural Sector

The government has anchored its strategy of building a climate-resilient agricultural sector on two key priorities: 1) water management, including irrigation expansion and measures to improve water-holding capacity such as watershed management and soil and water conservation activities and 2) climate-resilient infrastructure, covering transport and electricity. Beyond investment, additional support through grants and subsidies may be necessary to promote research and development in greener and more resilient agriculture such as heat- and disease-tolerant breeds, dry farming, and other climate-smart agronomic practices.

Nevertheless, weak alignment between several policies and strategies and limited coordination across different agencies and tiers of government during implementation have led to suboptimal outcomes in climate-smart agriculture and smallholder farmer development.

Another priority for the government is to expedite its land reform policy and secure land tenure for smallholder and emerging farmers. This should increase opportunities for these farmers to own productive assets and their motivation to invest in irrigation schemes and other infrastructure, as well as sustainable land management and related climate-smart measures.

Such initiatives should be accompanied by capacity-building programs, including financial support, for these farmers and their communities. The private sector has also launched a few initiatives to help farmers adapt to climate change and so complement the government's efforts.

The estimated investment needs for adaptation measures in agriculture are about 0.2% of GDP or R453 billion in net present value between 2022 and 2050. About 50% of these costs will arise from investments in irrigation programs, while the remainder will be divided between retrofitting and new investments in transport infrastructure (45%) and research and development (5%). These figures are aligned with those from the International Food Policy Research Institute (Sulser et al., 2021).

Recommendations

- Reduce the risk of water stress for farmers. This will require increasing investments in irrigated agriculture and reducing costs of existing schemes. Potential interventions include installing solar-powered rainwater-harvesting ponds, rehabilitating smallholder irrigation schemes, and expanding existing commercial irrigation, including public schemes and farm-led irrigation within hydrological limits. Watershed-based interventions will increase water retention and build climate resilience more broadly through pasture improvement, landscape restoration, biomass enterprise development, and community agroforestry. These initiatives can also generate job opportunities for unskilled laborers.

  The co-benefits could be maximized through better intergovernmental coordination and alignment of fiscal transfers and subsidies to local governments, communities, and farmers.
- Accelerate security of land tenure among smallholder and emerging farmers by improving land transfer mechanisms, ensuring new landowners have the necessary skills and support to succeed. Strengthen land administration to expedite transfer of ownership and security of tenure, and facilitate partnerships between smallholder and emerging farmers, and larger commercial farmers along the agriculture value chain.
- Consider carbon credits for generating revenue for farmers. Using carbon credits would require farmers to adopt green standards and guidelines and a credible monitoring, reporting, and verification mechanism. Building on the recently published green finance taxonomy, the government can identify a set of climate-smart measures and practices in agriculture that could be linked to carbon credits. Those could become a source of income for local rural communities through a transparent trading system as experimented, for example, in Australia and Kenya.
- Further promote cooperation between the public and private sectors. Partnerships should be considered for infrastructure projects such as water distribution and other joint activities, including testing and liming soil to ensure more effective fertilizer use, implementing conservation tillage, and preparing grazing plans for communal livestock investments.

- Research and develop heat-tolerant breeds and seed varieties, strengthen animal and plant nutrition and health to deal with changes in disease incidence, increase use of digital technologies to improve yields and increase efficiencies, and adopt regenerative agriculture as important factors for increasing the climate resilience of this sector.
- Promote inclusive agricultural insurance programs. Such programs could support farmers by: 1) serving as a proxy for collateral for farmers to access credit and 2) protecting them against climate catastrophes. Good statistics and information tools are needed to develop adequate insurance products and their pricing, including by collecting real-time data with automated weather stations and upgrading agricultural statistics portals.
- Strengthen the resilience of the fisheries and aquaculture sectors. This could include: 1) adopting new adaptive management measures (such as feedback control systems governed by rules), 2) empowering fishers to participate in decision-making and management processes, 3) developing early warning systems, and 4) improving energy infrastructure to maintain diurnal temperature variation of intensive aquaculture production systems.

Resilient Cities: Vulnerabilities and Adaptation Measures

South African cities are highly vulnerable to floods, urban heat, and droughts. These climate risks are expected to worsen in the future, with up to 19% of the urban population exposed to flooding by 2050. Concurrently, some metropolitan areas could experience a 10% reduction in precipitation, increasing the likelihood of major drought episodes. The damages from climate risks could be substantial as about two-thirds of the population is urbanized, and industrial and service activities are highly concentrated in urban centers.

Recent experiences from the Cape Town “Day Zero” drought and recurrent flood damage in KwaZulu-Natal have demonstrated that damages are localized, including within cities, with poor households in townships and informal settlements disproportionately affected. Those damages are compounded by inadequate urban spatial planning, infrastructure development, and energy policies. Urban policies that promote transport-oriented densification and green infrastructure could reduce damages. A recent study estimated that the exposure of the population to flooding and landslides will be reduced, by 10% and 2%, respectively, in SA’s six major metropolitan areas if such urban policies were implemented (World Bank, 2022).

Investments and Policy Reforms Required for Climate-resilient Cities

The general framework for coordinated planning and implementation of climate actions in cities is guided by the National Climate Change Response Policy (2011), the NDP, the Spatial Planning and Land Use Management Act (2013), and the Integrated Urban Development Framework (2016). Moreover, NT’s Cities Support Programme was developed to support the scaling up, alignment, and integration of adaptation strategies in cities’ investment plans for infrastructure and service delivery. At the city level, most metropolitan areas have developed climate action plans and have policies, strategies, pilots, and data for promoting sustainable, resilient, and inclusive urban development.

To build more resilient cities, the government is focusing on better land-use planning and compact city development. Such an approach promotes shorter traveling distances and better access to municipal services, thus facilitating social inclusion. It reduces water consumption and the costs of waste management. Better land-use planning and densification policies can also help avoid developments in risk-prone areas, while green infrastructure is expected to build resilience and minimize infrastructure damage and disruption of services during flooding. Digitizing city infrastructure and transport management systems can also help to reduce wastage and improve efficiency. Finally, investments in densification and green infrastructure offer additional social and environmental benefits, such as low traffic congestion, clean air, job creation and lower costs of providing services for municipalities (C40, 2022).

Achieving compact urban growth will require improved coordination. At the local level, South African municipalities are constitutionally mandated to provide a wide variety of services (such as electricity, water, sanitation, solid waste, and local roads construction and maintenance), but many have insufficient funding and human resources to fully develop climate-smart projects. They will require both financial and technical support from the national government.

Implementing climate-smart policies in SA's six metropolitan areas will cost an estimated 0.3% of GDP per year or R581 billion in present value between 2022 and 2050. These estimates assume that the incremental cost of adaptation policies is approximately equal to 20% of the total cost of urban investments (R2.6 trillion in net present value) required over the next 25 years.

Recommendations

- Align climate change and development policies between national and municipal authorities. Building resilient cities should be the responsibility of local authorities, but many measures will require coordination with neighboring provinces and the national government. Expediting the implementation of the country's Integrated Urban Development Framework will provide an inclusive governance framework for decision and implementation processes.
- Integrate spatial planning in adaptation strategies to reduce vulnerabilities for the population and lower the cost of adaptation measures. The World Bank Group has developed an urban planning tool to assess exposure to risks and city-wide impacts of climate resilience policies that local government technical staff can use.
- Strengthen urban resilience to floods and droughts. The main climate risk for urban centers is associated with water management and access, which will require retrofitting existing infrastructure and investing in new projects (if possible, in partnership with the private sector). Improving water demand management will require closely engaging with local communities through education and information programs and using incentives/ sanctions to promote responsible behaviors.
- Develop people-centered interventions by engaging local communities in determining climate adaptation priorities, including

disaster risk management and evacuation procedures. A key people-centered intervention is the NT's City Support Program's township economic development program and the Department of Cooperative Governance and Traditional Affairs' small town regeneration program, both of which promote houses and neighborhoods that are livable and climate resilient.

The Macroeconomic Damages of Climate Risks and the Costs of Adaptation

To estimate the overall economic damages from climate risks, a standard macro-structural model was adapted by introducing four damage functions (Burns et al., 2021). These functions include: 1) built up capital and land asset damages due to floods, 2) rainfed crop damages due to changes in temperature and precipitation, 3) livestock damages due to heat stress and availability of grazing pasture due to drought, and 4) labor productivity impacts due to heat stress. While these functions incorporate some of the major risks faced by SA, they are not exhaustive as they do not account for the broader impacts of water scarcity on the economy, the potential damages on human capital (education, health, and social protection), or possible economic tipping points. By contrast, the damages from tropical storms and rising sea levels have not been incorporated because they are not expected to significantly impact SA's economy before 2050.

While five major global climate scenarios (Shared Socioeconomic Pathways (SSPs)) were selected to assess SA's future climate projections, the results are only presented for the pessimistic scenario—SSP3- 7.0, dry. The overall damages derived from the forecasting model are expected to be relatively limited for SA's economy, amounting to around R1.5 trillion in net present value between 2022 and the end 2050, or on average 0.8% of GDP. They will, however, increase over time, reaching up to 1.2% of GDP per year between 2040 and 2050. Climate damages related to heat shocks on labor productivity account for 80% of total damages across the four channels considered.

The relatively moderate vulnerability of SA's economy to climate risks is explained by its moderate exposure to sea-level rise, at least until 2050, and to tropical storms. These two risks tend to account for the biggest economic damages globally. In addition, agriculture accounts for only 2.9% of GDP in 2021, when it is a major economic sector in many developing countries. Finally, the country benefits from relatively resilient infrastructure and good-quality buildings.

However, these overall estimates of damages mask significant variations both geographically and across income groups. The spatial distribution of damages from climate risks will be uneven across provinces. Damages are also expected to be bigger in major urban centers, where most economic activities and the population are concentrated, with the poorest households disproportionately affected.

The CCDR used two complementary methodologies to estimate the costs of adaptation measures needed to address the country's climate vulnerability. First, using a top-down approach following a methodology developed by the World Bank Group, the annual financing requirements to upgrade the country's assets are equal to 3% of their value (Hallegatte et al., 2017). The adaptation cost following this methodology would amount to about R1.8 trillion in net present value over the period 2022–2050, or an average of 0.93% of GDP per year. Second, using a bottom-up approach by adding all the financial requirements estimated for water, agriculture, cities, and road infrastructure in the preceding sections. Using this approach, the total adaptation cost would amount to R2.4 trillion in net present value between 2022 and 2050, or about 1.3% of GDP per year. While these two figures should be interpreted with caution, they are quite similar.

The bottom-up approach indicates that the most important costs will be in building a resilient water system, followed by resilient cities and transport. It also shows that the financing requirements in the water sector will be higher between 2022 and 2030 than in the next decades given the urgency to address SA's water challenges upfront.

Reforms in fiscal policy and management can reduce the cost of investing in adaptation. Given the "public goods" nature of the necessary investments, there is a need to improve public investment management and increase coordination across different tiers of government to enable the emergence of economies of scale in the design, implementation, and resourcing of green infrastructure projects. Horizontal coordination at both the national and local levels is necessary to align annual budget planning with medium-term investment planning, and recurrent expenditure (for operation and maintenance) with capital expenditure. Using internationally compatible guidelines and a taxonomy for adaptation projects improves their transparency and comparability and helps mobilize resources. New investments from existing and new firms can be encouraged by making climate information, associated risks, and instruments to address them available, promoting disclosure of information, lowering barriers to entry, and using the right pricing signals.

These measures should be complemented by targeted actions on climate-related investments, including:

- Conducting periodic risk assessments of public assets and contingent liabilities owned by general government institutions and developing the use of markets and insurance instruments.
- Improving the efficiency of climate-resilient public investments by: 1) introducing performance indicators for the allocation of fiscal transfers from the national government to provincial and local governments, 2) systematically tagging and monitoring those expenditures in the budgets of the national and local governments, and 3) evaluating projects using a social welfare-equivalent discount rate (in contrast to a market-based discount rate) to enhance rapid interventions.
- Adopting green public procurement procedures such as construction standards or land-use regulations that explicitly account for climate risks.
- Enhancing the PPP legal framework to create incentives for greater private sector participation in climate resilient-infrastructure projects by allowing risk-sharing on investments in new technologies, innovative business practices, and climate-smart performance-based contracts.
- Considering tax incentives to stimulate private operators to spend more on improving the resilience of their own assets or to expand their investments for the well-being of the community through corporate social responsibility measures.

SA has already initiated some of these measures, but it is important to operationalize them at scale. In addition to these cross-cutting fiscal measures, the government can use financial sector policies to stimulate more and better climate-resilient investments from both the public and private sectors.

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Sustaining the Inner Niger Delta Lifeline

by Chris Baker[1], Peter de Koning[1], and Mori Diallo[1]

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Key Messages

- Natural wetland systems in the Sahel provide significant economic value for millions, but this is typically not factored into sectoral water management investment decisions.
- Water resource management solutions of the past for food and energy security may not provide the desired security for the future.
- Decision-making around infrastructure investments to drive economic development need to be informed by a more holistic understanding of the economic pros and cons.
- With the unpredictable effects of climate change, ensuring livelihood and food security is not about (water) control but about flexibility to adapt: water resilience supports economic resilience.
- Solutions for the future need to be people- and ecosystem-based and need to be flexible, contextual solutions rather than fixated on time and place.

Introduction and Background

Wetlands provide significant economic value locally, nationally, and sometimes regionally. The Upper Niger Basin (UNB) and Inner Niger Delta are one large iconic, wetland system that extends across the Sahel delivering natural resource-based services to millions of people. Their health is dependent on the hydrology of the water systems that they are connected to, which typically drive seasonal flooding that in turn supports traditional and increasingly intensifying use of these services. Rice production, fisheries, and livestock raising are all typical uses that form the foundation of the wider economy in these areas. Growing population pressure, a strong need to drive socio-economic development based on increased water use, and growing impacts from climate change are driving growing water insecurity which is placing these systems at risk. Despite their importance, decision-making around water resource management remains rather sectoral and often takes insufficient account of the wider social and economic impacts.

Mali and Guinea are among the world's poorest countries, with persistent water, food, and energy insecurity. As in the wider Sahel belt of Africa, population growth is outpacing food production. Demand for food and energy is rising. To support their people and economy (GDP) Guinea and Mali want to increase their energy and food production and future security. Guinea and Mali are planning a new dam project on the Niger River in Guinea, and large-scale expansion of irrigation by the Office du Niger (ON) in Mali. Construction of the dam was announced in 2017, but since then little further action has been taken. At the time the case study was completed in 2020, the preferred dam size was 396 m high above sea level with a storage volume of 2.8 km^2 and a reservoir surface area of 287 km^2 (the medium option (Wetlands International, 2020)). The location was Folon, 30 km upstream from Fomi. This Fomi Dam is intended to take advantage of hydropower potential and to store and divert water for agricultural irrigation, providing a secure supply of water throughout the wet and dry seasons. An Environmental Impact Assessment has not been published yet and it is not clear if or how this plan will proceed.

This case summarizes the results of a study conducted by a Malian and international partnership including Wetlands International and others in close participative consultation with Malian government ministries and agencies. The study assessed the potential impacts of this infrastructure development according to the dimensions outlined above. It illustrates that economic resilience is also about water resilience in the Inner Niger Delta. The case shows the social and economic risks of designing and operating traditional, sectoral infrastructure in a context of water insecurity and a changing climate. It points to the need to make more strategic environmental assessments of such investments that take a holistic approach and embed the results in the wider economic sphere.

Climate Change

The landlocked countries Mali and Guinea already have significant variability in annual rainfall and experience regular droughts. For Mali, the annual mean temperature is 28 oC with a maximum of 51 oC and a minimum of 10 oC (MFA, 2018). Already the mean average temperature in Mali has increased by 0.7 oC and is expected to rise even further with differences per region and season. The frequency of hot days has not risen significantly (yet), but the frequency of hot nights did, except for during the winter. Rainfall has been decreasing since 2001 and the mean precipitation is changing. Mali has been getting less rain, ranging from 200 mm in the North (expanding to the South) to 1200 mm in the South (from averages previously above 1200 mm). The mean annual rainfall is projected to change further from -22 to +25% by the 2090s. However, with the current emission levels, we will reach 2 oC before 2050 (Climate Adapt, 2015). This means water availability becomes more unpredictable with large variations in time and place.

The Niger River Basin

The Niger River Basin covers a total area of more than two million km^2 and runs through nine countries. It is the main river artery of West Africa, flowing from the highlands of Guinea to its most northern point in Mali and back south to its delta outlet in Nigeria. It is the principal freshwater source in this semi-arid to arid Sahel region, making it crucial for the provisioning of a wide range of ecosystem goods and services along its route to many different beneficiaries. Even with some dams already in operation, the basin is still characterized by high natural variability, with extended periods of wet and dry years. Climate change and increasing temperatures are adding uncertainty to the amount of water that will be available in the future.

The Inner Niger Delta's (IND) functionality is integrally linked to the river flow arriving from the upstream river basin. It is characterized as a flood pulse driven system. The seasonal expansion and contraction of lakes and wetlands in the IND depends on the river inflow at the entrance of the delta: Ké-Macina for the Niger River and Sofara for the Bani River. The Niger River receives most of its runoff from rainfall in its headwaters in Guinea, located more than 600 km upstream. The Bani River contributes approximately 21% of the total inflow into the delta and is fed by precipitation in southern Mali and Cote d'Ivoire. Local precipitation in the IND is relatively low and contributes only a limited amount to the annual flooding cycle, meaning that the flood extent of the IND is largely dependent on precipitation in the upstream areas. In the wet season, from June to November, the IND transforms from an arid environment into a vast wetland landscape with few dry places at the height of the floods, before de-flooding again over several months.

Economic Contributions

In 2021, agriculture contributed around 33% to Mali's Gross Domestic Product and employed nearly 80% of Malians (many as subsistence farmers). The IND is a major economic asset in the Malian and regional economy. It is estimated to contribute approximately 8% of Mali's GDP (based upon estimates of its value to agriculture, livestock raising, fisheries, transport, and associated processing described below). In a country with low levels of education and scarce opportunities for non-agricultural employment (20%), millions of people and animals currently depend on the goods and services produced by the seasonal floodplain wetlands of the IND. Two million people (10% of the national population) live there permanently, and many others seasonally migrate there from dryland areas.

While covering only 1.6% of Mali's land area, the IND provides about 15% of national cereal production (Ministère du Développement Rural, 2016) 30% of rice production, 80% of fish production, as well as dry season grazing for up to 60% of Mali's cattle. Its unique location and ecosystem make it possible for farmers to grow crops farther north than anywhere else in the West African Sahel. Pastoralists and cattle from some neighboring countries move into the IND in the dry season, while fish from the IND are exported across West Africa. Primary and secondary production in the delta depends on the flooding (timing, extent), which has a significant impact on sustaining fisheries, agriculture, livestock, and housing. The flooding is rainfall, climate, and water management related.

Agriculture

For more than 90% of the farmers, agricultural production is important for subsistence. Farming in the delta is highly dependent on the combined effects of the rainy season and flooding periods. Cropping types, distribution, and yields are greatly defined by the date on which rainfall and flooding starts, the duration of the flooding period, the maximum water level, and the speed at which de-flooding occurs (Thom and Wells, 1987). Agriculture in the delta is mostly focused on rice and millet production. While rice is highly dependent on flooding and irrigation, millet and other important cereals such as fonio, maize, and sorghum are more dependent on rainwater availability.

Various irrigation techniques are used for rice production (30% of the national production) including: 1) rain-fed, 2) flood recession, where crops are planted on the moist floodplains after the flood recedes, 3) water levels being controlled in simple polders along the river, and 4) small-scale pump irrigation schemes (Pearce 2017).

Traditional floodplain rice production (yields) can vary greatly between years as it strongly depends on water availability as well as inundation zones and water depths (with an optimal depth 1–2 m). Rice production in the Mopti region can easily decline from about 400,000 tonnes in a wet year like 2010–2011 to about 100,000 tonnes in a dry year like 2007–2008. Compared to natural floodplain rice production, crop yields can be doubled when water is slightly managed, as with flood-controlled irrigation. In comparison, when land is fully irrigated the yield may be boosted up to six times. Normally, such a yield improvement requires higher agricultural inputs (e.g. fertilizer, labor, mechanization) and hence may also happen in the IND with the right sort of investment. However, at the same time it must be said that the water productivity (defined as the amount of yield produced per unit of consumed water) of irrigated land is under debate, with huge irrigation losses due to canal seepage and non-beneficial evaporation.

Fisheries

About a third of the population in the IND catches fish for either subsistence purposes or to sell on the market: 4% depend exclusively on fisheries, while more than 30% have a diverse livelihood with a combination of fishing, pastoralism, and/or agriculture. For fisheries, the Mopti region is most important (Schep et al., 2019). The delta produces 80% of Mali's fish and fish are exported across West Africa. Total fish trade in the IND is estimated to be between 10,000 and 50,000 tonnes and is also related to the flooding of the IND (Zwarts et al., 2005). The total value of fisheries (traded and auto-consumption) in the entire delta is valued at between 50 and 95 billion West African CFA Franc (FCFA) per year (Schep et al., 2019).

Livestock

The IND supports millions of cattle, sheep, goats, horses, and camels. It is highly productive for livestock, not only because of its size, but also because of its flood dynamics, grazing across the delta during the flood recession, through a practice known as "transhumance." Twenty percent of the 20 million goats and sheep and 60% of the five million cows in Mali are concentrated in and depend on the IND and its surroundings during the dry period (Wetlands International, 2019). The current economic value of livestock raising — including meat and milk production, animal sales, and leather — calculated for the regions of Mopti, Tombouctou, and Ségou, represents an annual total of about 250 million FCFA.

Socio-Economic Relevance

Housing, energy, and medicinal herbs
The vast majority of the local population collects clay to build and maintain their houses (94%). About 85% of delta inhabitants collect firewood to meet their own energy needs. Collection of herbs and tree-related products — natural products used in traditional medicine — is carried out by almost half of the respondents. Availability has decreased over the past five years (69% in the case of trees, and 87% for herbs).

Transport and navigation
Transport by boat is important for both commercial, social, and leisure purposes in the delta (e.g., access to local markets and medical, financial, and agricultural service providers). Passengers and freight are primarily transported by two different types of boat: the ferry and the pinasse (a traditional wooden boat). Ferries only operate during the wet season as they require a minimum of 3–4 m of water depth for navigation. The pinasses run through into the dry season until the water level becomes too low even for these smaller boats, which require around a meter of water. Based on the day rates and the average number of navigable days per route, the total annual value for fluvial transportation can be estimated at around 2.1 billion FCFA for the Koulikoro-Mopti route and 1.6 billion FCFA for the Mopti-Gao route.

Relevance for Biodiversity

The IND is one of the major wetlands in Africa, and the floodplain ecosystem sustains people and nature. The delta has exceptional ecological value and is a globally important biodiversity hotspot; it is designated as a Wetland of International Importance under the Ramsar Convention. Seasonal flood patterns are crucial in maintaining the biodiversity of the area (Klop et al., 2019; Wymenga et al., 2017a and 2017b). For instance, the area is of paramount importance to both resident and migratory bird species (Zwarts et al., 2006). At least 27 species of migratory water birds are seasonally present in very high numbers. The numbers of colonial breeding water birds in the central lakes are amongst the highest for wetlands in Africa. The IND's Acacia kirkii flood forests and the Acacia seyal forests at the fringes of the delta are home to high densities of migratory land birds, hosting many European species from the Red List of the International Union for Conservation of Nature (IUCN). The survival of wintering birds and reproduction of resident birds is directly related to the flood pulse dynamics of the IND, as expressed by the extent of the flooded area and the depth of the water. In turn, healthy ecosystems are central to the provision of the services that support community livelihoods and the delta's economy.

Office du Niger (ON)

The ON is a semi-autonomous government agency that administers one of the largest and oldest (since 1932) irrigation schemes in Sub-Saharan Africa. Water from the Niger River is diverted into a system of canals upstream of the IND at the Markala Dam, 35 km downstream of Segou and used to irrigate nearly 100,000 hectares. The production targets for 2017–2018 were set at one million tons of paddy rice, 350,000 tonnes of vegetables, 30,000 tonnes of corn, 47,000 tonnes of potatoes and 5,000 tonnes of fresh fish from floating cages, ponds, and rice-fish culture (if producers are provided with the needed certified seeds and quality organic and mineral fertilizers). ON is considered the rice bowl of West-Africa. Even so, the country still relies on imports of rice and wheat to avoid food insecurity (on average 540,000 tonnes per year). The livelihood situation of farmers in ON is not clear (no recent figures) but poverty seems less in ON compared to the national level. However, the average farm size is approximately 3.7 hectares with a low level of production due to a lack of fertilizer and poor water management. The bulk of the marketable surplus seems to come from a small number of farms with large irrigated areas. There also seem to be tensions between farmers and ON administration regarding (collective) water management and water user fees.

The Ambition

While Guinea has long desired to build the Fomi reservoir for electricity to support both its growing population and the energy needs of its mining industry, its most recent proposed design makes it multifunctional. A key secondary goal is to guarantee water for downstream irrigation expansion. Water released from the Fomi reservoir for hydropower generation during the dry season and then diverted at the Markala barrage would enable the ON to irrigate more land, supporting improved food security.

Fomi is therefore a key priority for the governments of Mali and Guinea and included as a priority investment in the Sustainable Development Action Plan of the Niger Basin Authority (NBA, 2007). In Mali the construction of Fomi is supported by the Ministry of Agriculture as a prerequisite to extend the irrigated area of the ON. To meet increasing demand for food, the Malian government proposed an expansion of the ON in the Study of the Agricultural Development Programme of the Office Zone du Niger, 2014–16 (PAHA IV). The goal of the ON is for it to become the rice granary for West Africa. Its current production of 740,000 tonnes across an irrigated area of about 1,300 km^2 generates 52% of national rice production. In total, the PAHA outlines the ambition to expand by an additional 3,300 km^2 over the coming 20+ years; 2,000 km^2 by 2025, 3,100 km^2 by 2035, and almost 4,600 km^2 by 2045. This ambition corresponds to an annual extension rate of 90 km^2. By comparison, over the last 10 years expansion has averaged 40 km^2 per year. Adding 3,300 km^2 will result in a significant increase in potential cereal production, projected at two million tonnes, including 1.2 million tonnes of rice — an increase of 58%. The total annual irrigated area will be even more as some areas will be cropped more than once a year. Based on these ambitions, the total irrigated area in 2045 will be about 5,400 km^2. The area earmarked for expansion is currently sparsely populated with livelihoods related to the flooding dynamics of the delta. With the expansion of the ON, these people will be displaced to other areas, but it seems unlikely that they will benefit from employment in the new development.

This ambition needs to be looked at through the lens of water availability. Over the period 1961–2000, only 67% of the current irrigation water demand of the ON would have been met, leaving a gap of 33%. Looking at the dry and wet seasons separately reveals that the deficits in the dry season are up to 43% and therefore on average quite substantial, whereas wet season irrigation supply deficits amount to only about 3%. Technically, the available water in the Niger River would allow the ON's expansion plans to be realized during the wet season. However, the plans also propose an intensification of crops such as off-season rice and perennial sugarcane in the dry season. A further extension of the ON's area in the dry season is not possible under current conditions and can only be achieved by either increasing irrigation efficiency or by supplying more water from the Niger River. Supplying more water by diverting the Niger River at Markala is not possible without the construction of a large new dam like Fomi for water storage upstream.

Impact of the Fomi Dam and ON Expansion on Production

Additional water infrastructure as currently planned in the Niger Basin will store and divert large volumes of water and hence have impacts on river discharges into the IND. The hydropower dam changes the flow regime by increasing discharges during the dry season and decreasing discharges during the wet season. In effect, it slowly flattens the flood curve and reduces the pulse that drives the delta's ecosystem and economy. The extent to which the flow regime is altered depends on the reservoir's dimensions and operations.

Operating Fomi purely for hydropower generation would increase the dry season discharge into the delta. Compared to natural flow conditions these would go up between 12% (small dam) and 156% (large dam). However, when this extra water released during the dry season from Fomi is diverted to expand dry season irrigation as planned by ON, the low flows entering the delta at Ké-Macina will be reduced below the level of natural flows. Taken together with the existing Sélingué Dam, this study showed that diverting water to meet the projected irrigation demands of the ON would reduce low flows by 58% in 2025, 91% in 2035, and 98% in 2045. In the case of a large Fomi Dam, the low flow would change from a 156% increase under 2015 irrigation conditions to a 78% reduction under 2045 irrigation projections compared to natural conditions. This reduction in low flows increases the risk from stagnant water bodies in the IND and could dry up the delta significantly.

History shows that a complete dry up of the IND would lead to a collapse of the ecosystem and food production. Projections also show that the assumption of double cropping in the ON would not be sustainable with available water frequently being insufficient. These changed inundation dynamics will determine the total amount of ecosystem services that can be provided in the delta. The median flood peak would be reduced to a level comparable to 1987 — the year with the second-lowest peak simulated in the period 1961–2000. This resulted in an inundation of 350 cm and flood extent of 10,000 km^2. In the IND, it would compromise the productivity of the ecosystem for the population. Fisheries in the Mopti region would decrease by 24%. The amount of cattle, sheep, and goats that could be sustained in the region would decrease between 5% and 13%. For the more than two million people living in the IND, this would mean diminished economic prospects and increased food and water insecurity. The number of navigable days with ferries and pinasses in the delta would on average go down by 17% between Mopti and Koulikoro and even up to 33% between Mopti and Gao. A smaller delta also provides less habitat for flora and fauna. Secondly, with livelihoods providing less food security, people resort more to wildlife hunting, leading to huge stress on local populations of birds and mammals and on areas like flooded forest for construction, energy materials, and traditional medicines.

Based on recent hydrological model simulations it is evident that if the Fomi Dam project is built and ON irrigation is expanded as planned, the inundation dynamics in the delta will see a shift towards a higher number of drier years compared to the current situation. The frequency of very dry years is estimated to increase from 24% to 29%. Irrigation expansion will have an even larger impact. If more water is diverted for irrigation by the ON, the frequency of very dry years could increase to 42% — almost one out of every two years.

The probability of disaster years will also increase substantially. In the current situation, these occur once every 50 years. In the scenario with an operational Fomi Dam and expanded ON irrigation, the frequency increases by a factor of five — to once every 10 years. In a worst-case scenario, the combination of a Fomi Dam, expanded irrigation, and a very dry year would reduce peak flows below levels ever seen and completely dry up the IND, leading to a complete collapse of the ecosystem and affecting the two million people whose livelihoods are based upon this ecosystem. It is highly unlikely that households in the IND could move to this new irrigated area in ON and profit from the development. This would be a humanitarian disaster with famine and widespread migration.

Impacts of Fomi Dam on Migration and Conflict

There are three livelihood strategies for people in the IND: intensification, diversification, and migration. The local and regional context determines whether (seasonal) migration is negative or positive for the economy, but it does put stress on families and livelihoods.

Life in the IND has always been a delicate balance including adjusting to the natural variation of the region's climate and its implications for water security. When changes to the IND's service provision affect the livelihoods and local economy, people will be forced to consider alternatives including migration and/or increased competition for natural resources. The sustainability of livelihoods for fishers, farmers, and pastoralists in the IND depends greatly on whether they have access to and control over various types of assets like the water, fish, soil, and fodder provided by the wetlands, along with other assets like technologies, information, and financial resources. Farmers also need access to fertilizer (either in the IND or in ON). Access to assets strongly influences which strategy people choose to either maintain or boost their livelihood. For each of these three livelihood strategies, migration increases for every decrease in water level in the delta. A considerable share of farmers and fishers would abandon their occupation and permanently migrate to a different region, country, or continent if they considered the water level to be too low. In a situation with maximum water levels at Akka above 500 cm (a constantly a wet year), less than 10% of interviewed farmers said that migration would be a likely strategy to sustain their livelihood. With decreasing water levels, more and more farmers consider migration a viable sustainable livelihood strategy, going up to 20–40% in cases of maximum water levels of 350 cm (a very dry year).

Pastoralists are less influenced by the water level. At the lowest level of 350 cm, 16% of pastoralists expressed a willingness to permanently out-migrate, while more than 40% of the fishers of Tenenkoun and Ké-Macina agreed that permanent outmigration was the most viable strategy under these conditions. In scenarios that result in a higher occurrence of dry, very dry, and even disaster years, consideration of permanent outmigration as a preferred sustainable livelihood strategy increases. In a scenario with a large Fomi Dam and ON irrigation at 2045 projections, 21% of farmers, 24% of fishers, and 10% of pastoralists would be willing to out-migrate.

Tensions and conflicts arise when communities seek to use the same water and land for different livelihood seasonal strategies (e.g., farming, herding, fishing). This leads to widespread discontent and provides fertile ground for extremist groups to exploit. The water stress caused by the effects of climate change, overexploitation, and upstream management decisions results in behavioral change amongst communities in the delta as they seek new coping strategies, which in turn trigger more tensions and conflicts, and is detrimental to production and the economy.

Lessons from the Past for Climate Adaptation

The Upper Niger Basin has historically experienced large annual and decadal variation in rainfall and resulting fluctuations in river discharge. The 1960s are considered wet years characterized by high precipitation and river discharge. From 1969–1992, the Sahel suffered the Great Drought (known locally as La Grande Sécheresse). During this prolonged drought, the flooded area of the IND averaged only 11,000 km^2. People and nature could not adapt. The drought triggered severe famine in the Sahel and increased desertification. In 1984, the IND only reached an inundation of 8,000 km^2, or one-third of its maximum range. While the IND was a relative haven during the drought compared to the rest of the Sahel, the carrying capacity of the ecosystem and its services collapsed under the pressure of too many people and livestock and too few resources. Most of the delta's flood forests suffered overexploitation and some were entirely destroyed. Also, the production of bourgou, a staple fodder for livestock that grows with floodwater, was disturbed when there was little or no rainfall to initiate its growth ahead of flooding. Many cows died and herders lost more than half their cattle due to reduced food resources and the reduction of the inundated area.

Climate change is likely to result in increased temperatures for the region along with unpredictable changes in precipitation. Simultaneously, the population is growing. A new drought period would affect a larger population with more destructive consequences.

Synthesis: Water Resilience for Economic Resilience

The Inner Niger Delta and wetland systems like this across the Sahel have significant social and economic value from local to national scales. A key characteristic of the IND is its seasonal dynamics that underpins the economy. The annual cycle of flooding and de-flooding is integral to the IND's regional economy, which is based on farming, fishing, and pastoralism and supports significant biodiversity and a diversity of livelihood strategies (including seasonal migration). Increasing food and energy production and security in the Sahel is essential to address the needs of the growing population. Because water plays such an important role in sustaining livelihoods, new water infrastructure should also be "conflict-sensitive" (Wetlands International, 2019). While irrigation can provide water security for agriculture and will continue to be a major part of the mix of measures to safeguard food security, the times are changing. Solutions that worked in the past will likely not work in the future due to climate change and its disruptive impact on people, ecosystems, and water infrastructure operations. Climate change will increase local temperatures, the variability of rainfall, and the magnitude of extreme weather events (e.g., droughts and floods).

The current strategy in the IND, predominantly focused on the realization of large-scale irrigation and hydropower, will bring undoubted benefits but also carries substantial risks and associated costs. Foreseeable consequences range from diminished livelihoods and biodiversity loss to an increase in instability, heightened risk of conflict, and increased outmigration from the region. Safeguarding and optimizing the role of the IND needs to be central in future thinking around planning and investment. Furthermore, this demands measures to ensure that water-related investment, strategy, and policy work to maintain such critical natural systems as part of development solutions rather than risking depleting them and creating risks and problems. Currently in Mali there is some limited consultation on such initiatives, but they are predominantly sectoral driven, and environmental impact assessments — when they are carried out — do not expose the full range of issues and implications to the economy and society as a whole.

People living in the IND have traditionally used a combination of intensification, diversification, and (seasonal) migration. The existing culture of diversity in livelihood strategies is also the basis for an adaptative, flexible coping mechanism to build on. A holistic, ecosystem-based and human-rights based approach to integral water management of the IND plus improving ON's irrigation efficiency and using less water-intensive crops may underpin Mali's development and food security ambition and provide a lifeline to the people in the IND.

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Water Resilience for Santiago de Chile

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Key Messages

- Chile's economic resilience is facing a critical challenge from water scarcity, which has been intensified by growing vulnerability to drought. Water demand has surged due to a period of robust economic growth and the country's heavy reliance on water-intensive industries. The mining sector alone was expected to increase its demand for water by 45% in 2020.
- Social resilience is also threatened by droughts. In 2021, the fourth driest year in Chile, more than 50% of the population, or 19 million people, resided in an area that was severely affected by water scarcity.
- An expected increase of 3 °C in temperature due to climate change is predicted to cause several impacts, including droughts, turbidity events, and reduced water availability from glaciers.
- Government reforms implemented in 1990 have allowed private operators to enter the market and facilitated financing of over US$ 2 billion for investments in wastewater treatment plants. Currently, the Chilean water production and reuse market is fully privatized.
- Privatization has enhanced the market's competitiveness, overall

water quality, and contributed to cost reduction as well as continuity to the point where the country now has 100% coverage in both drinking water and sanitation. For example, Aguas Andinas is the largest water and sewage utility in Chile that serves around 40% of the Chilean population.

- Chile has achieved 100% treatment of its urban wastewater, which is an important step towards sustainability. However, there is an opportunity to further enhance economic resilience by transforming wastewater into a productive resource which is currently not utilized.
- The private sector's role in promoting water resilience goes beyond providing water-related services. It includes assuming responsibility and leadership for responsible investment that prioritizes sustainability and environmental protection. Also, improving the efficiency of water resources and communicating responsible use protocols to their consumers.

The Climate Change Challenge

Chile, a South American nation, has emerged as one of the most prosperous in the region. Its economic strength and solid institutions have successfully weathered three major shocks: namely social unrest in 2019, the COVID-19 pandemic beginning in 2020, and the 2022 Russian-Ukrainian war. In spite of these shocks, its economy actually experienced growth by 11.7% in 2022. According to the World Bank (2021), Chile has one of the swiftest recoveries worldwide despite the remarkable contractions it witnessed — particularly following the social unrest.

Nevertheless, the Chilean economy remains challenged by high inflation, widespread inequalities, population growth, informal employment (affecting one-third of the workforce), and environmental challenges. The Chilean Ministry of the Environment states that the country is highly vulnerable to climate change. Its effects are already being felt in the national territory. Climate projections for Chile show that the main effects are a rise in temperature and a decrease in precipitation. Thus, an increase in the frequency of extreme events such as droughts and river and coastal floods is highly likely.

Chile is ranked as the 10th most water-risk-prone country out of 142 countries (4th among OECD nations, trailing only the US, Mexico, and Australia) (OECD, 2017). The northern part of the country is arid and semi-arid and is projected to see its temperatures increase in the next century, while experiencing more frequent warm storms that produce mudslides and episodes of high turbidity in the basin of the rivers. This will have negative impacts on its main productive activity: mining. The most affected area of the country will probably be the central zone, where the capital city Santiago is located. In the coming decades, precipitation reductions of around 20% and temperature increases of 3 °C are expected in this area. This will have important effects on the most densely populated area of the country — an area that also includes a dense concentration of its agriculture, forestry industry, and hydroelectric power. Some of the effects in drinking water production are described below:

- **Drought**: Central Chile is suffering two decades of uninterrupted drought. As a result, freshwater sources have experienced a continuous decline. At present, the

Metropolitan Region has a worrisome structural water deficit (gap between available water resources and the real needs of the area) of up to 250 cubic hectometers under certain hydrological conditions. This is a situation that will continue over time and could even worsen. For this reason, it is fundamental to increase efficiency in the use of water resources and adding more water resources to the productive matrix.

- **Turbidity events**: Increased turbidity in the upper basin of the rivers has a significant impact on drinking water production and has a high probability of affecting customer supply. Turbidity events are classified into four groups: 1) winter rainfall events, 2) summer rainfall events, 3) snowmelt, and 4) extreme rainfall events (atmospheric rivers). The snowmelt event in particular is associated with the increase in temperature without the occurrence of precipitation that causes increased river flow, which in turn causes increased sedimentation.
- **Reduction in the availability of water from glaciers**: Glaciers undergo changes in response to variations in other components such as climate, volcanic activity, and human action. These modifications are mainly evident in their geometry, volume, thickness, mass balance, and their contribution of liquid water to the ecosystem. Due to the more severe effects of climate change and the prolongation of the drought affecting the central zone, glaciers in the Metropolitan Region are losing volume at an accelerated rate, among other alarming changes. In central Chile, 65.4% of the glacier surface is located below 4,000 m above sea level. When the temperature in the valley reaches 30 °C, at that altitude there is a positive temperature of about 10 °C shortly after midday — enough to melt several meters of ice at the end of a warm summer. But glaciers are not only melting faster due to warming; they are also losing more ice by sublimation due to increasingly dry conditions, and the higher elevations fail to recharge with sufficient snow during the winter. Initially, as it melts at a faster rate, a glacier contributes more water to the basin, but only until it reaches a critical point: when it begins to decrease its water yield due to its smaller size. This puts the water supply for the city of Santiago at risk, especially in summer, when 70% comes from glaciers.

The Threat of Water Supply to Chile's Economic and Social Resilience amidst Climate Change Challenges

Chile's economic resilience is facing a critical challenge from water scarcity, which is being intensified by growing vulnerability to drought. In the past few decades, Chile has experienced a surge in water demand, largely due to a period of robust economic growth and the country's heavy reliance on water-intensive industries such as mining, agriculture, forestry, and fish farming. For instance, Chilean Copper Corporation reported that the mining sector alone is expected to increase its demand for water by 45% in 2020, while forecasts indicate that agriculture will require an additional 4 km^3 over the next 40 years (COCHILCO, 2009).

Water challenges have direct or indirect repercussions on most of the country's productive activities. In 2020, the reduction in copper production was primarily caused by supply-side issues such as water restrictions. This has diminished Chile's exports.

Social resilience is also threatened by droughts. For example, 2021 was the fourth driest year in Chilean history. More than 50% of the population, or 19 million people, resided in an area that was severely affected by water scarcity. In fact, according to the study "De Estructuras a Servicios" sponsored by the Inter-American Development Bank (IDB), Chile is the country with the highest proportion of its population living in basins with water stress and will continue to be in the next decades.

Certainly, Chile's economic and social resilience relies significantly on fulfilling the water requirements of its water-intensive industries and residents.

Private Sector as a Key Enabler in the Chilean Water Production and Reuse Market

During the 1980s, Chile underwent a range of free-market economic changes, one of which was the transfer of control over the country's water and sanitation services from the government to private corporations. This means that it is now the responsibility of private entities to deliver these vital services to the public.

Privatization has been very beneficial to the water sector in Chile. One of the benefits of privatization is that it can lead to increased efficiency and investment in the sector. Private companies have the incentive to provide high-quality services to customers to remain competitive and profitable. This can result in improved infrastructure, better water quality, and more reliable service for consumers. According to the regulator´s 2021 annual report, 96% of the Chilean customers were served by companies operated by international private groups, with SMAPA the only relevant state-owned company operating in urban areas.

Full Treatment of Wastewater

Wastewater rates in Chile in the 1990s were on the order of 20%. At that time, the government's plan to improve wastewater treatment rates included reforms that allowed the entry of private operators starting in 1998 and helped finance more than US$ 2 billion in investments in wastewater treatment plants that allowed 100% of urban wastewater to be treated. Given climate change, proper treatment is only the first step in developing a sustainable approach to transforming wastewater into an economic resource. Although Chile currently treats 100% of its wastewater, it does not use it productively. In fact, most of the treated wastewater ends up in the sea. The environmental and economic potential of changing this is enormous: the total volume of unused wastewater could cover almost 10% of the country's total hydrological deficit.

Water Continuity and Improved Water Quality

The country currently has 100% coverage in both drinking water and sanitation. What's more, Chile is one of just two countries in Latin America where the U.S. Centers for Disease Control recommends tap water to be safe to drink. According to a World Bank survey, in spite of the high water stress of the country, just 1.8% of the water companies report water supply shortfalls — one of lowest rates among surveyed countries. Additionally, and consistent with the survey mentioned, according to the Chilean Water National Regulator (SISS) the urban areas of the country have a level of continuity of the service of 99.7%.

Reduced Costs of Water and Sewage Services

One of the most prestigious and up-to-date sources of tariffs worldwide is the Global Water Tariff Survey prepared by Global Water Intelligence (GWI). According to that study, the average global water tariff is 2.34 USD/m^3. The water tariff is composed of fixed and variable charges for drinking water, wastewater, and rainwater collection. Summarizing the GWI data by adding the fixed, variable and tax costs, we conclude that worldwide costs for potable water, sewage collection and treatment, and rainwater collection including taxes are as follows:

- Drinking water: 1.27 USD/m^3
- Wastewater: 0.95 USD/m^3
- Storm water: 0.11 USD/m^3

In turn, the regional composition of tariffs is as follows. In Latin America and the Caribbean, the average tariff is 1.85 USD/m^3. Only the cost of potable water in Latin America and the Caribbean reaches 1.47 USD/m^3. Sewage charges are only 0.38 USD/m^3, probably due to the low level of sewerage (and even less sewage treatment) in most Latin American countries. The cost in Santiago de Chile is 1.23 USD/m^3 (drinking water is 0.59 USD/m^3 and wastewater is 0.65 USD/m^3). The cost in Santiago de Chile represents 1.4% of the basket of products of the average household.

The success of the wastewater treatment plan is due to several measures:

1. New emission standards that began to regulate pollutants associated with the discharge of liquid industrial waste into sewage systems and the discharges of liquid waste into marine and inland surface waters
2. Strengthening the supervisory powers of the Superintendencia de Servicios Sanitarios (SISS) in 1998
3. A new regulatory framework that allowed private capital in the sector's companies.

The government's efforts resulted in benefits not only in public health, quality of life, and environmental protection, but also in economic benefits. Specifically, the decrease in wastewater irrigation has increased the potential of the tourism industry and the export potential of agricultural products. From 2000–2017, private companies invested US $2.3 billion in wastewater treatment, allowing Chile to reach treatment levels comparable to the most advanced countries in the world.

Aguas Andinas Sewage Treatment Facilities

Aguas Andinas is the largest water and sewage utility in Chile. It provides services to around 40% of the Chilean population. Its service areas are in the Santiago Metropolitan Region, where there is 100% coverage in drinking or potable water and 100% sewage collection and treatment. It is a subsidiary of Veolia Group.

In 1999, only 3% of Santiago's sewage was treated; the rest was discharged into rivers together with industrial liquid waste. In turn, the Mapocho and Maipo Rivers were persistent sources of disease and unhealthy conditions in the capital. In 2003, with the inauguration of the La Farfana Treatment Plant, this scenario began to change. Then the Mapocho-Trebal Complex was added, and in just 13 years the city was able to treat 100% of its sewage. Thanks to investments of more than US$ 1.2 billion, enteric diseases such as cholera and hepatitis were eradicated, urban spaces were recovered, and riverbanks were repopulated with wild species.

This is the great contribution of the water and sewage industry to the Metropolitan Region. As part of this process, between 2007 and 2010 the company executed the "Mapocho Urbano Limpio" project, a US$ 113 million engineering program that, as of 2011, made it possible to definitively close the 21 sewage discharges that previously fed into the urban channel of this river. It consisted of the construction of a subway interceptor collector of up to 3 m in diameter and 29 km in length, which runs parallel to the riverbed.

The process of decontaminating wastewater to make it fit to be returned to natural watercourses or used for irrigation, in accordance with the standards required by law, is carried out in two biofactories (former sewage treatment plants where residues have been transformed into products): the Trebal-Mapocho Complex (228 million m^3 in 2021) and the La Farfana Plant (247 million m^3 in 2021), and in twelve plants located in different localities around Santiago (34 million m^3 in 2021).

The application of a model based on the circular economy makes it possible to recover the sanitary waste resulting from the purification process carried out in biofactories. Organic waste separated from water during the purification process is used in agriculture and in the regeneration of degraded soils, either directly as biosolids or after processing at the El Rutal Plant, where it is transformed into a dry fertilizer. Some 30,000 hectares benefit from these biofertilizers. This area is likely to multiply in the coming years. The biosolids go through three drying processes at El Rutal: solar, chemical, and resting. The final product has better agronomic properties than wet biosolids due to a higher availability of nutrients thanks to the mineralization generated by the biological process of biosolids. Until December 2021, biosolids from El Rutal were still considered waste and, although they could be used for agricultural purposes, they had to comply with the protocols of the National Waste Declaration System. This will no longer be necessary; in January 2022, the Agriculture and Livestock Service (SAG) certified them as fertilizers. This will speed up their commercialization. In the past year, the first sales of the product were made in this quality and agreements are expected to be signed soon. It is a product with a high nitrogen, potassium, and phosphorus content, as well as a high organic levels, high stability, and very good granulometry, which makes it easier for the plants to absorb the nutrients.

Another by-product of wastewater treatment is biogas, a fuel composed of methane and carbon dioxide, which is generated by the biodegradation reactions of biodegradable organic matter. It is currently used to heat boilers at the plants and to produce energy for self-supply, providing electricity consumed by the Mapocho-Trebal Biofactory. In addition, a sufficient volume is injected into the Metrogas network to supply around 40,000 households in Santiago.

Private Sector's Role in Promoting Water Resilience

In the Santiago Metropolitan Region, the most evident effects of the climate crisis are associated with a drought that has lasted more than a decade and an increase in heavy summer rains in the Andes Mountains. The following section will shed light on the role of Veolia, a private sector company, in terms of facing climate change challenges.

Turbidity Events

One effect of climate change is the increase in intense summer rains of short duration in the Andes, which cause displacement of materials that, when falling in the flows, cause high turbidity in the Maipo and Mapocho Rivers, affecting the production of potable water in Aguas Andinas Plants. In order to reduce the main associated risk (the supply cut), the company is investing in major infrastructure works with a goal to increase the autonomy of potable water supply to 48 hours. To this end, the company has invested in new reservoirs, pipelines, and wells. This has resulted in an increase in autonomy from four to 34 hours in a period of seven years. One relevant project was the inauguration of six mega-tanks at Pirque in November 2020, with a capacity of 1.5 billion liters of reserve water. These works made it possible to face the last major turbidity episode, which occurred in January 2021, without supply cuts.

New wells to produce drinking water were also inaugurated. Completed in 18 months, the works consisted of 14 wells with a depth of 300 m, a 20,000 m^3 tank, and a lifting plant. This investment of US $33 million will provide an extra 1,500 L/s for the supply of more than 400,000 inhabitants of the southern area of Santiago, as well as increasing from 34 to 37 hours of autonomy in the production of drinking water in the event of extreme turbidity in the Maipo River. The wells operate remotely and are automated to guarantee a safer service and stable pressure.

In turn, the El Manzano-Independent Intake project will further complement water autonomy for the region, operating during instances of extreme turbidity events. It will help secure water without sediment for the production of potable water, tapping into the El Manzano sector 5.7 km upstream of the current Maipo independent intake and providing a flow of 16 m^3/s to the Las Vizcachas production plant. In addition, it will allow filling the Pirque Mega Ponds, adding another 6 m^3/s available for the production of potable water at the La Florida and Padre Hurtado Plants. The project is currently in the environmental assessment, design, and engineering stage.

Droughts

Central Chile has suffered more than two decades of uninterrupted drought. As a result, freshwater sources have suffered a continuous decline. At present, the Metropolitan Region has a worrisome structural water deficit (gap between available water resources and the real needs of the area) of up to 250 cubic hectometers under certain hydrological conditions. This is a limiting situation that will continue over time and could even worsen. Veolia has studied future scenarios, including demand and the behavior of water sources, and its conclusions anticipate a worsening. Given this scenario, Aguas Andinas has defined a range of actions aimed at reducing the water deficit by 2026 through three ways:

1. **Increase efficiency in the use of water resources**: Through its practice of measuring water use throughout the value chain, the company has been able to outline concrete actions to increase water efficiency which reduces the volume of raw water needed to meet the same demand. These actions have concentrated on three priority areas:
    a. **Optimization of raw water intake**: The actions taken by the company to optimize surface water catchment, such as the incorporation of more gates in the rivers, have allowed this activity to be near its maximum level of efficiency. On the other hand, measures are also being applied to implement state-of-the-art water management of the company's 250 extraction

wells. Following a successful pilot plan in 2020 and a corresponding tender in 2021, in January in 2021, a four-year project was initiated with the goal to digitize the wells alongside a more efficient management methodology that will allow us to have more water, less energy consumption, and better control of the associated risks.

b. **Greater efficiency in drinking water production plants**: The advances in operational management issues carried out in 2021 allowed the company to continue advancing in its water efficiency strategy during the following year, achieving new reductions in the levels of losses of the drinking water production plants. The statistics for the year indicate progress. In 2022, 200 L/s of raw water were recovered, reaching a loss margin of 4.8%, a figure 0.9% lower than in the previous period.

c. **Greater efficiency in detecting and repairing leaks**: Around 30% of the drinking water produced by the company ends up as unaccounted for or unbilled water. To address this, the company has a Water Efficiency Plan that is a set of initiatives that seek to speed up the detection of leaks and their repair — tasks that require enormous efforts given the extension of more than 13,000 km of underground network that feeds homes in the capital. In 2021, it was concluded that annually the company was able to detect and repair a number of leaks similar to those produced by the natural deterioration of the network. To break this cycle, in 2022 a project was started to double the detection and repair capacity through new technologies and methods. In the 12 months of its implementation, the recovered water for leaks found and repaired grew from 200 to 500 L/s.

2. **Adding more water resources to the company's matrix**: Since there is a limit to the efficient use of resources, there comes a point when it is necessary to look for other alternatives. Considering this reality, the company is pushing for a series of infrastructure projects and agreements with other users in order to increase the contribution of water to its matrix.

   a. **Groundwater extraction**: Over a three-year horizon, the company aims to increase the amount of potable water produced from underground sources from 15% to 30%. To this end, it has already implemented several medium-sized projects, adding around 800 L/s to its matrix. Even some sectors in the western and southern areas of Santiago, which had a mixed supply, now have a supply based exclusively on underground resources. In addition to the above, the Cerro Negro-Lo Mena wells add 1,500 L/s to water production.

   b. **Collaboration agreement with irrigators of the first section of the Maipo River**: The yield of Aguas Andinas' rights on the Maipo River (27% of the total) is no longer sufficient to supply the city of Santiago. The most feasible solution to alleviate this deficit is to make more surface resources available, which was achieved thanks to an agreement signed in August 2021 with the seven irrigation associations that have rights to use the first section of the river. This agreement is historic for several reasons: for the first time the different users in this sector of the basin recognize the existence of a structural problem that requires a joint and long-term response. Usually, each year the company coordinates with the irrigators to maintain the volume of the El Yeso reservoir, which protects Santiago's water supply, at a safe level, but this new agreement guarantees the permanent availability of the water resource and provides sustainability to the basin through initiatives with an integrated approach. Its most important points include a diagnosis of the management of the first section of the river, which is in charge of a surveillance board, to ensure the maximum level of efficiency. Human consumption is prioritized over other water uses, and if the city's supply requires it, the irrigators will contribute water at a fair price. The agreement entails an obligation to make the necessary water transfers to maintain the safety levels of the El Yeso reservoir and establishes a flow curve that meets the demands of all parties involved. Aguas Andinas commits to implement projects that will make the use of the basin sustainable, including the reuse of treated sewage and the drilling of emergency wells in the irrigators' canal strips to contribute to irrigation. The development of a master plan for the basin by all parties will also consider the future evolution of demands, rainfall, and flows, with a view to ensuring its long-term sustainability.

c. **Reuse of treated water in the bio factories**: The company is studying a series of projects to apply the principles of the circular economy to the region's water supply. The most relevant involves treated water from the Mapocho-Trebal Plant and was included in the agreement with irrigators. The objective is to efficiently and optimally manage the basin, maximizing the availability of water in an equitable manner and allowing a balance in water availability. The project includes a connection from the Mapocho-Trebal Biofactory to the Irrigation Associations of the First Section of the Maipo River, who, in turn, will provide the equivalent of raw water from the river to supply the city, increasing the availability for human consumption. The project is going through the environmental evaluation, design, and engineering stage, and its materialization is scheduled for the next few years. It received a great boost when it was included in the collaboration agreement and obtained the approval of the authorities and different interest groups. It should be noted that, at present, treated flows from the biofactories are already being used for irrigation, but downstream of the biofactories.

Another initiative under study is the infiltration of treated water into the region's underground aquifers to prevent the prolonged drought from depleting their natural recharge capacity. Although it has not yet been scheduled to begin, it is gaining increasing public consensus.

3. **Responsible use campaigns**: A comprehensive solution to water scarcity also requires the involvement of end consumers. For this reason, the company carries out a series of actions to raise awareness in the community about the urgency of using water responsibly.
    a. **Every drop counts**: To reach residential consumers, Aguas Andinas deploys campaigns through its digital networks and constantly reinforces its presence in the media, alerting about the drought and its consequences. On October 25, 2021, it launched the most recent massive campaign for responsible use, which aimed to change the habits of its customers. With the slogan "Every drop counts," companies and other economic sectors such as agriculture and every household in Greater Santiago are invited to join in the care of water.
    b. **Coordinated management with municipalities**: For the last three years between November and April, in view of the large volume of water that municipalities allocate to irrigating green areas, Aguas Andinas delivers to each mayor of the region a report with the detailed consumption of public spaces so that they can check for water leaks. Since 2020 this campaign has shown a positive evolution. That year for the first time the consumption of maintenance of green areas fell, which until then showed an upward trend. This was achieved thanks to concrete measures, such as the replacement of lawns with low water consumption species in squares and the installation of digital meters to monitor irrigation in green areas.

Increasing Resilience for an Uncertain Future

Chile's economic and social resilience relies significantly on fulfilling the water requirements of its water-intensive industries. Unfortunately, the country is facing remarkable water scarcity, which is being exacerbated by an increasing vulnerability to drought. Chile's economic growth has contributed to a surge in water demand in recent decades due to heavy reliance of industries such as mining, agriculture, forestry, and fish farming. However, the challenge of water scarcity is impeding the country's productive activities. For instance, in 2020, water restrictions caused supply-side issues that led to a reduction in copper production, thereby decreasing Chile's exports.

Droughts also threaten social resilience, and in 2021, over 50% of the population (19 million people) lived in areas severely affected by water scarcity. According to a study sponsored by the IDB, Chile is currently and will continue to be the country with the highest proportion of its population living in basins with water stress in the coming decades.

Addressing the challenges of climate change requires promoting efficiency in consumption, increasing water efficiency, promoting water reuse, generating new water sources, and preserving the quality of water sources. It is also essential to have a regulatory framework that promotes not only efficiency, but also risk mitigation, encourages investment, facilitates and accelerates the execution and financing of new works, and promotes water savings while maintaining the self-financing of the companies. Investments are needed in reuse of treated wastewater, desalination, infiltration into aquifers, reduction of water losses, lining of canals, reservoirs, wells, and nature-based solutions.

The private sector plays a crucial role in the development of innovative solutions and the implementation of sustainable practices for efficient and effective management of water resources. Within the water sector, they can contribute significantly to the implementation of adaptation policies and programs to address water-related challenges. Private sector operators possess the necessary expertise, access to cutting-edge technologies, and sustainability credentials. As a result, their involvement can facilitate the development of cost-effective solutions and help mitigate the impact of water scarcity with less costs and more efficiency.

Despite the lower availability of water in Chile, the drinking water and sewerage companies have maintained high levels of coverage, continuity of service, and quality standards. Likewise, thanks to the works executed by the private sector, problems due to floods and turbidity events have been avoided. Key attributes to successes were the Chilean regulatory framework and tariff structure that incentivized the private sector to operate in transparency. The private sector companies also assumed responsibility to drive change by not only implementing projects for water reuse and drilling wells for underground water, but also raising awareness amongst residential consumers and deploying water usage awareness campaigns through digital networks.

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Water Resilience for Economic Resilience in Spain: A Critical Crossroads

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Key Messages

- Spain's economy is significantly dependent on natural resources, particularly water, the availability of which is progressively decreasing due to climate change.
- Climate change projections indicate a gradual decline in water resources and heightened climate variability, including increased frequency and severity of droughts and floods. This is coupled with escalating temperatures, greater evaporation losses, and an increased demand for water in irrigation and agricultural applications.
- The economy of southern Spain is strongly reliant on agriculture and tourism, both of which require the scarce water resources that are under threat from climate change. Tensions emerge between agricultural expansion and other industries, such as tourism, biodiversity preservation, energy generation, and urban applications.
- The energy sector, especially hydroelectric and biomass, faces significant vulnerability to water availability challenges. Uncoordinated reactions to water insecurity are undermining resilience

against future disruptions while water diversification initiatives such as transfers and groundwater utilization have inadvertently intensified water insecurity and diminished water resilience.

- Desalination and wastewater reuse exhibit promise; however, they are impeded by substantial costs and preferential treatment towards freshwater sources.
- The growth of Spain's economy has relied on extending water supply facilities and infrastructure, which have underperformed. Water management organizations are adapting to enhance water distribution, entitlements, and cross-sector collaboration, aiming to harmonize economic and environmental requirements.

Introduction

Spain is a relatively affluent economy that has relied heavily on natural resources throughout its history. The case for water reliance in Spain refers to an overarching adaptation problem of managing a unique resource with limited (when not diminishing) supply, set against the backdrop of increasing uncertainty due to climate change. The scope of changes experienced is already intense and potentially irreversible. Some aquatic ecosystems may become unable to continue to carry out their current functions, including services such as water provision that are integral to the economy itself (Marshall, 2013).

Spain is certainly at a crossroads for water that needs to be given high priority by economic decision makers. The structure and stability of the economy is at stake, affecting economic sectors in different ways depending on their location.

Climate change scenarios, despite their uncertainty, point to a progressive reduction of water resources in Spain. In the worst-case scenario, an approximately 24% reduction in average river flow is forecast for the end of the century with respect to the reference series 1961-2000, with possible reductions from 30–40% in the most sensitive areas. The reduction in aquifer recharge is estimated in similar proportions (NCCAP, 2020). There is also a substantial decrease in snow reserves that naturally regulate the water cycle.

All studies also predict an increase in climate variability. This points to an expected increase in the risk of droughts, which will be more frequent, longer, and more intense, and floods, with more frequent swells and higher peak flows (NCCAP, 2020). Episodes of torrential rain may be accompanied by geomorphological imbalances in basins, which may lead to a more accelerated siltation of reservoirs, with the consequent reduction in their capacity, accentuated by the need for flood mitigation measures. It is expected that 50% of flood-prone areas will be worse off. Furthermore, hydraulic infrastructures have been designed with safety margins that, in some cases, could be exceeded because of climate change

Rising temperatures will also increase evaporation losses from reservoirs, which could double in the coming decades. The increase in evapotranspiration because of increases in temperature, together with the possible extension of the irrigation season, will lead to more demand for irrigation and agricultural uses, which already account for more than 70% of total demand in Spain.

In addition to agriculture, the energy sector is highly exposed due to its dependence on water availability. The expected impacts are relevant, and of a negative nature, in the hydro and biomass sectors. A significant reduction in hydroelectric production is expected as a consequence of reduced river flows.

The negative consequences of spontaneous, individual, reactive and unplanned responses to water insecurity are already visible in the most water stressed parts of the country. The main examples are the race to exhaustion in the use of groundwater, the illegal water markets, and the investments in new irrigation projects, whether legal or unauthorized. These responses to more scarce and more uncertain water resources can only come at the expense of reducing resilience to existing uses and future shocks. A planned, anticipated, and coordinated response is a basic precondition to restore the water resilience of important regions of the Spanish economy.

Water Exploitation in Spain

All Spanish basins suffer a certain degree of water stress. Around half of the Spanish territory, the Mediterranean basins, and Atlantic Andalusia currently suffer from severe water stress, which, combined with the typical irregularity of the Mediterranean climate, entails significant exposure to droughts.

The most serious case is that of Segura where “normal” demand is 132% of average annual resources, despite the contribution of transfers from other basins, desalination, and direct and indirect reuse. These extremes do not hide the high exposure of the severely water-stressed basins of the Jucar (95%), the Guadiana (62%), the Ebro (59%), and the Guadalquivir (55%) (Pulido-Velazquez et al., 2021; Marcos-García and Pulido-Velazquez, 2017).

Water in “the Model” of Economic Development

Water has always been a critical factor in Spanish economic development. Despite low and variable rainfall throughout its history, Spain has been able to harness the potential of water for economic development mostly for agriculture, power generation, tourism, and urban development. The other side of the coin is that the Spanish economy, and more particularly its most competitive areas (and those that have proved to be more resilient to the current world economic crisis such as agriculture and tourism) are heavily exposed to changes in availability of water resources.

Freshwater sources in Spain are intensively used, mostly in the most water scarce areas where populations and the most water-intensive activities tend to concentrate (Pulido-Velazquez et al., 2020). In all these places, local incentives and comparative advantages have triggered expansions in water demand that cannot be met with the renewable resources at hand. This is the case of the Mediterranean basins in Spain that require, on a regular basis, a quantity that largely exceeds their long-term water renewable resources. Under these conditions of water development, a binding condition for economic progress has required comparatively higher levels of infrastructure investment and sophisticated institutional arrangements from the onset.

Infrastructure has generally expanded water supply services everywhere and at the required volumes, widening opportunities, reducing production costs, and providing water, energy, and food security while allowing for the concurrent progress of all other sectors in the economy (Cook and Bakker, 2009; Grey and Sadoff, 2007; Vörösmarty et al., 2021). Gradually, the marginal return of projects has decreased as the supply of water is more or less taken for granted and waterborne (and other water-related) risks are abated.

Few other places in Europe offer more convincing evidence of the importance of water for economic progress. Harnessing the productive potential of water has traditionally been a major challenge for economic development in most of the Spanish territory. Apart from the Atlantic catchments in the North, Spain presents all the features of a semi-arid Mediterranean climate with low rainfall (85% of the EU average (EEA, 2014)) and a high potential evapotranspiration (amongst the highest in the continent) that make this country the most arid in the EU, with an annual runoff half the EU average (CEDEX, 2017). High inter-season and inter-annual variability increases the management complexity of Spain's hydrological resources.

Historically, the main strategies of river basin authorities have focused on supplying water services to support areas of the economy including population change, urban growth, irrigation development, manufacturing activities, etc. The main objective of water policy consisted of finding inexpensive and reliable means to meet water demands.

Infrastructure was designed, built, and operated with the best knowledge at the time and assuming the normal variance of precipitation patterns around normal or average levels of rainfall. With the benefit of hindsight, ex-post evaluations show all water storage systems have performed below expectations for two main reasons: the lack of coordination across sectors and the overestimation of future water resources.

Addressing water scarcity has involved incentives to increase water availability by transferring water from further away territories. Paradoxically, water transfers have been more successful in increasing water demand than in increasing water resilience in water-scarce areas. They have also performed below expectations in adding more water to the balance. More recently, water desalination has become part of the supply mix. Installed capacity today is at 5 million m^3/day. Desalinated water is used as a buffer stock during drought events.

Water institutions have evolved throughout time while dealing with issues such as water allocation, definition, and enforcement of water use rights (Mathews et al., 2022; Grey et al., 2013). Other focal areas of water institutions include making norms, providing basic water services, monitoring water quality, developing technical skills, and coordinating investments as part of a progressive strategy of economic development (Garrick et al., 2019). This supply-oriented modus operandi is currently in a transition towards a new one aimed at making all water services used by the economy consistent with the preservation and adequate protection of the ecological status of water bodies.

The importance of water as an economic asset for the different sectors of the economy

Agriculture comparative advantages

The Spanish economy has many different competitive advantages in specific sectors. In agriculture these advantages include a relative abundance of arable land. Spain has 261,000 km^2 of agricultural land — the largest in the EU only after France — representing 52.9% of the total area as compared to the EU average of 43% (EUROSTAT, 2022). Spain also benefits from an above-average amount of daylight hours and below-average labor costs (in terms of the EU). It is also partly explained by an elastic labor supply fed with immigration for many years. Still, water is the most critical and scarce factor for agricultural production.

The economic importance of agriculture is higher in water-stressed areas

The export-oriented commercial agriculture that dominates water-scarce Mediterranean basins in Spain requires more and more sophisticated inputs and labor skills, follows modern entrepreneurial practices, and supplies basic commodities to a complex and competitive agrifood manufacturing and logistics industry. On the contrary, traditional agriculture requires limited labor and manufactured inputs. Its management practices do not demand sophisticated commercial and financial services and its output does not feed complex industrial processes or supply chains. It has other benefits for biodiversity conservation and leisure activities, including tourism.

Since water is the main driver of the transformation of the agricultural model, this in turn has become the basis of a complex economic structure. In regions like Andalusia or Murcia, the direct contribution of agriculture to the regional output and employment (4.2% and 4.5%, respectively) might be low (although higher than average), but its indirect and induced impact over the whole production chain make it the central piece of the existing income and employment opportunities. For example, in Andalusia it is estimated that every additional euro generated by the sector generates two euros in the economy (output multiplier), and one job is created for every EUR 25,000 of additional output generated by the sector (Perez Blanco et al., 2010). In addition, this water-dependent sector has also performed better than the overall economy during recent crises. The employment share of agriculture in Murcia, Andalusia, and Valencia grew from 6.9%, 8.4%, and 2.8% in 2008 to 7.4%, 10.4%, and 2.9% in 2011, respectively. As a stark example, during this period agricultural employment in Murcia grew by 10.6% while the total employment rate declined by 10.6% overall.

Publicly coordinated water investments are associated with significant scale and scope economies (see for instance González-Gómez et al., 2014, for domestic water services). In other words, the social and economic returns of water development (indirect productivity) in the early and intermediate stages of water development are substantially higher than financial returns as perceived by individual users (apparent productivity). Economic returns of water development for parts of the Andalusia Region may be 3.1 times larger than its financial returns in the case of water for irrigation (92% of water consumption). In turn, this economic growth powered by water investments has the potential to induce significant water savings in the case of the manufacturing industry (Molinos Senante et al., 2021).

There are substantial differences in the productivity of the irrigation systems in water-scarce regions and those in relatively abundant regions. This explains the significant differences in the technical efficiency ranging between 81% for the Andalusian Mediterranean River Basins and 69% for the Guadalquivir River Basin compared to those of the relatively water abundant northern basins (between 53% in the Galicia Coast River Basin and 57% in the Ebro River Basin) (ESYRCE-MAPA, 2020).

Changes in irrigation techniques have been significant during the last decades. This has improved productivity. In 2002, gravity irrigation represented 40.5% of irrigated surface, sprinkler irrigation 18.4%, and drip irrigation 34.3% (other irrigation systems accounted for 6.9% of irrigated lands); by 2020 the more efficient drip irrigation already represented 54%, sprinkler irrigation 23%, and gravity 23% (ESYRCE-MAPA, 2022).

Competitiveness of Tourism

In 2021 Spain was the number one destination in Europe for international tourism with a share of 15% of the total number of nights spent in tourist accommodation establishments across the EU (EUROSTAT, 2023). The number of international tourist arrivals in Spain for 2022 was 71.6 million (INE, 2022). The economic boom of the last decade boosted the availability of rooms (which grew by 32.1% since 1999 until the sudden decline of the economy in 2008) (INE, 2014) and second residences (which grew by 87.7% in the period 2001–2011) (INE 2020). In 2022, the number of people affiliated with Social Security from the tourism industry amounted to more than 2.4 million, or 12.2% of the total (TUESPANA, 2023), a figure that reflects its importance in the national economy.

The direct contribution of the tourism sector to the Spanish economy was EUR 97.1 billion (8% of GDP in 2021). It included 2.3 million jobs, or 11.4% of employment in Spain (INE, 2022). Employment is even higher (up to 18%) when considering all inputs and the complementary services used by this industry (IET, 2020).

Tourism is concentrated in the dry season (i.e., summer months) and in the most water-scarce areas. This season coincides with the holiday period of European visitors. Almost 70% of total tourism is concentrated in the islands and the Mediterranean coast. Two of the main mass tourism destinations in Spain (and the first and fourth top 20-European tourism destinations in terms of nights spent), namely the Canary and the Balearic Islands, do not have permanent rivers.

The development of storage and desalination infrastructures combined with groundwater has provided a reliable supply of water services, which is a critical input for tourism and for the development of accommodation and amenities such as swimming pools, gardens, and golf courses. There has also been an increase in the demand of complementary services in the tourism package, such as food and beverage, travel agents, transport, banking, and other economic activities that help sustain the local economy.

Increasing competition for water resources along with reductions in water availability and pollution from intensive agriculture production — which has developed in the same regions of Spain as those preferred as tourist destinations — are already leading to financial losses in the tourism sector. This is the case in the area of the Mar Menor. The Bank of Spain estimated that home prices in the Campo de Cartagena area diminished 45% in real terms since 2016 due to the ecological crisis of the lagoon (BDE, 2021). The Bank calculated a wealth loss of EUR 4,150 million in the region as compared with a scenario without the ecological crisis.

Energy production valuable but below expectations

The Spanish economy required 75 years and considerable resources to develop the existing hydroelectricity capacity. The installed potential is 16,000 Gigawatts. This is a remarkable record. But if we look at the actual electricity produced, it may seem a complete failure. After 75 years of hydroelectricity development, the whole system is only able to produce a fraction of the energy that was produced 75 years ago when these infrastructures were not in place. The difference is that back then there was water.

The general conclusion after 75 years is that the remarkable development of hydropower has been more effective in maintaining the production of electricity than in increasing or even stabilizing electricity production. This outcome would have been different if hydropower development had been coordinated with agricultural and urban development, reducing the need of heavy infrastructures and coordinating water demands. With time, once the margin for new infrastructure to ensure water supply has been narrowed by decreasing returns, this option to improve water resilience cannot be an option.

Pathways Toward a Water-Resilient Economy

The objectives of the water transition to a resilient and sustainable pathway in Spain are still a matter of discussion and will require reaching political agreements, as well as coordination of different policy areas.

Decoupling the economy: Structural transformation of the economy

With the existing resource constraints and overall generalized impacts on water, Spain cannot continue growing with the same rates of intensity of water use in the economy. It is essential to decouple growth from increases in the demand of water. To do this, the relative importance of the different sectors has to change, especially in those regions where climate change is going to affect the availability of water resources the most.

To date, the Spanish economy has not been successful in decoupling economic growth from water use. Although water use per capita has remained stable (770 m^3/capita/year in 2009 according to OECD (2012)), some river basins still use water in excess over long-term renewable resources. For instance, the Guadalquivir and Segura River Basin's ratios of water abstraction over renewable resources are 1.64 and 1.27 according Pulido Velazquez, et al. (2021) and the projections envisaged in the River Basin Management Plans do not show a change in this pattern. Although water demand in the Segura in 2021 was be very similar to that of 2009 (1,762.1 instead of 1,779.1 million m^3), water use is expected to grow by 5.2% (from 2,892 to 3,046 hm^3) in the Tagus River Basin, which supplies 17.3% of total water demand in the Segura (SRB, 2020).

Technological investments in decoupling the economy from water use have not always been successful. The National Irrigation Plan (2008) expected to be able to advance decoupling with projected savings of 3,662 hm^3/year and an investment cost of EUR 7.368 million (López-Gunn et al., 2012).

The overall conclusion is clear. To contribute to decoupling and to transition into a water resilient economy, water savings need to be transformed.

The drive of public budgets towards investing in infrastructure needs to be re-evaluated

The perception of water development and water investments generating economic growth as a key factor for rural development has led to the construction of bulky infrastructure designed to use resources as much as possible.

More needs to be invested in taking care of the existing resources or in protecting the water that is required for infrastructure to function properly. This requires an economic evaluation of water infrastructure decisions, comparing, for example, the cost-benefit ratios of different alternatives and analyzing their macroeconomic impacts. Benefits and macroeconomic impacts cannot be taken for granted.

There are other investments such as the protection of existing resources (and specially groundwater) and the diversification of water sources that are an opportunity to match water supply and demand while facing the deep uncertainties of climate change. They contribute to the goal of curbing water scarcity and provide an adaptive response to uncertain water supplies — provided that affordability concerns are addressed and adequate incentives are established.

Building a sustainable water portfolio requires rewiring policy decisions in the long term and making clear decisions over the size and composition of the water portfolio. Different sources of water should play different roles in the long term. Those decisions over the optimal water portfolio, prioritized on explicit economic criteria, need to be part of the adaptive policy pathways of the water transition.

Investing in a resilient future: Investing in co-benefits makes economic sense

Protection of groundwater must be a priority, not only because it is the most vulnerable resource due to the deterioration of its quality and increasing overexploitation, but also because it is a strategic resource for water management in situations of drought. It plays a fundamental role in the maintenance of aquatic ecosystems, providing the base flow of river systems. Its deterioration jeopardizes the environmental status of rivers and endangers the sustained provision of water services.

Increased groundwater depletion has opportunity costs. It is becoming unavoidable to invest in the much more expensive non-conventional water sources to ensure excess capacity in times of drought. This has effects in terms of costs of production, in the competitiveness of the economy, and opportunity costs in terms of allocation of the public budgets.

The recovery of the morphology and dynamics of watercourses is also an important investment for the future. It plays a key role in hydrological regulation and flood risk management. Actions such as nature-based solutions (NBS), sustainable urban drainage, including recovering meanders, reconnecting floodplains, renaturalizing watercourses, preserving wetlands, eliminating obstacles, promoting continuity, and recovering riverside forests should be promoted. These actions perform multiple functions and offer co-benefits such as reducing flood risk, improving biodiversity and the conservation status of ecosystems, recharging aquifers, protecting quality, reducing erosion, and improving soil structure.

Considering the marginal cost of the supplies to cope with droughts
Given the multiple uncertainties about water, it is important to recognize from the beginning that water transition would not be possible without adaptable policy pathways for harnessing the potential of opportunities to provide resilience to economic development. Flexibility could be facilitated by contingent and flexible water allocation rules for adapting water demands to available resources across time and space, improving adaptability while preserving the objectives of the water transition.

Diversification of water sources when properly designed and implemented could serve the objectives of the water transition. Water scarcity and the need to cope with more frequent droughts can be tackled with alternative sources at higher marginal costs (from reuse of reclaimed wastewater to desalination of brackish water and seawater). This is not a new option in Spain. Substantial improvement has been recorded regarding the increasing capacity to desalinate water. The installed desalination capacity is around 5 million m^3/day and could potentially supply water for a population of 34 million inhabitants (Zarzo, 2020).

However, given the high cost of desalinated water, its effective use has been limited in quantity. Less than one-fifth of installed membrane capacity is actually used, and it is reserved only for more valuable uses (mostly drinking water) in particular during dry periods. Non-conventional water is then used mainly for emergency situations, posing additional challenges for its financial sustainability, while overexploitation of freshwater sources may go on.

Assigning a substantive role to desalinated water in the supply portfolio is still a pending and a highly controversial issue. In practice, due to its relatively high cost, this source is reserved as a buffer stock for emergencies (i.e., droughts). This improves resilience to droughts although it represents a real challenge to the financial sustainability of operating plants.

Creating incentives to protect and conserve the resources we have

In the “business-as-usual” scenario, the incentives in place lead to the destruction of the cheap and easily available reserves of groundwater resources, which paradoxically are the most valuable as strategic reserves for the future. They are the ones best suited to act as buffer stock during droughts and to provide water security.

Water is a sector where scarce and unreliable goods are priced lower than their abundant and reliable substitutes, unlike microeconomic theory would suggest. In the business-as-usual scenario, continuous depletion of groundwater sources will take place until extracting reaches the price of alternative sources, even if alternative resources are available. There is then a pricing failure which translates into incentives in such a way that users prefer financially cheap but scarce and unsafe water sources rather than the financially expensive but relatively abundant and reliable alternative water sources. Should the problem not be recognized, the unavoidable transition from financially cheap to more expensive water sources would induce significant harmful effects on the environment and the economy. The real question is then how to preserve the “cheap” but most “valuable” resources, given that the baseline scenario can easily be anticipated, considering the incentives in place.

Considerable progress has been made thanks to the drought management plans in Spain. To some extent, they made drought response anticipated (rather than discretionary and reactive) and planned (rather than improvized) but needed to tackle the real problem: the control over an important part of the available water resources. Furthermore, higher constraints may also lead to higher incentives for over-abstraction, thus leading to lower buffer stocks and higher drought risk. These are clearly unwanted outcomes.

What incentives then may need to be established to provide water security so as to guarantee the resilience of the economy? How can incentives be created so that surface water abstractions by water users will remain close to renewable runoff (considering environmental flows) and demand in excess will be met from groundwater — exploited under unsustainable patterns but still less expensive than non-conventional sources?

The "use it or lose it" kind of incentives occur when farmers and other agents perceive the value of water but do not have any alternative to using it. This increases or sustains water demand, even when it is greater than long-term water supply. Prevailing incentives push sectoral demands up and make it difficult to close de facto the river basins to accommodate current uses within the range of available water resources. Perversely the "use it or lose it" framework may mean that new infrastructure is executed to consolidate the right to use local water resources.

Incentive and pricing schemes for a water-resilient economy

In this context it is important to make clear that water prices, subsidies, fees, and other financial instruments are not inherently good or bad but are simply instruments or means to the ends of water policy. Indeed, these instruments should provide the revenues needed to the financial sustainability of the provision of valuable water services. In addition to that, from an economic and policy standpoint, they should promote the behavioral changes needed for the water transition towards a water-resilient economy and discourage actions that harm water resilience.

The most important water policy challenge nowadays still consists of aligning the multiple individual decisions on using and preserving water with the common societal goals of paving a transition towards a resilient economy. In most cases what is rational from a private point of view is not necessarily such from a social or economic perspective.

Significant progress has been recorded so far in adapting water prices and making cost recovery of operational and capital expenditures more transparent. However, this progress refers mainly to urban water services.

Water prices are low when compared to the cost of marginal resources. Further progress is required in covering resource costs (in particular that relate to water scarcity) and environmental costs. There are frequently no adequate incentives for farmers to use water efficiently as water consumption is, to a large extent, not metered and therefore water charges are not linked to real consumption. There is evidence to show that farmers are reluctant to pay more for water. But contrary to perceptions, they report in some studies to be willing to pay an excess price between 0.16-0.18 €/m^3 for water security (Sala Garrido et al., 2020).

Self-abstraction is not charged. The energy cost of withdrawal in some cases provides an adequate incentive to halt overexploitation. In others, it has not been high enough to prevent, for example, environmental external effects on wetlands and other protected areas.

When water supply reduces and it is increasingly uncertain, individuals are more willing to pay for water security. They might actually be willing to transform their productive system in order to use less water and reduce its exposure to water shortages. This can include a shift towards crops that are less vulnerable to water deficits or, for example, they might be willing to pay for an insurance policy covering drought losses (Perez Blanco and Gómez, 2014). In this context, the role of pricing and cost-recovery mechanisms (as financial instruments to ensure the right incentives are in place), is still of paramount importance. Prices should actually make the best out of current opportunities through bridging efficiency gaps, inducing shifts towards less water-intensive activities, and using alternative supply sources to mitigate scarcity and increase the water resilience of the economy.

Economic activities and cities must be rewarded for contributing to water resilience and charged for worsening water security. Prices need to be designed as part of a decision-making architecture to lead people to make decisions that are consistent with an overall objective of economic resilience and environmental improvement.

Improve the existing insurance schemes

Actually, the main source of farmers' security is groundwater. Nature is paying the price of farmers' exposure to droughts. Production during drought years has been sustained at the expense of groundwater over-exploitation. Moreover, the prices of agricultural products have been seen to increase during droughts, leading to greater benefits for farmers.

However the financial system may be a better option than the overexploitation of groundwater during droughts. Some alternatives are being considered. Developing new insurance schemes, such as a drought insurance, might be a means to make the financial system stand up to preserve local income in drought-prone areas and make a real contribution to recover critical groundwater assets by freeing them of the duty of serving as income security instruments.

Use subsidies wisely: Getting subsidies right

The role of incentives is critical to deal with the affordability concerns arising anytime a new solution with the potential to contribute to the water transition comes into play. These concerns are the most visible barriers to the extended use of desalinated water, the adoption of water efficient devices, and the adoption of NBS and other water conservation practices in cities and rural areas.

Many alternatives can be used to overcome affordability barriers, but all of them should be implemented on the condition that the beneficiaries make a sizable contribution to the water transition. Similar to the energy transition and to the EU Green Deal, all the financial instruments to overcome affordability concerns should be integrated into a just transition strategy.

No doubt, affordability concerns need to be managed as a critical component to make the water transition politically acceptable in water scarce areas. But, dealing with affordability by subsidizing water services may increase water use and extend tensions to these new sources. In other words, subsidies make sense in a process of transition when they reduce pressures on over-exhausted water bodies (e.g., groundwater) or when they protect wetlands and biodiversity — providing co-benefits to the economy and society in a pathway towards more sustainable water use.

In relatively water-abundant areas, subsidies to capital costs of infrastructure and water supply systems lead — in a mature water economy like Spain — to the use of water in very marginal lands. This can create environmental impacts and reduce resilience of all other existing or potential uses for very little contribution to the economy. In individual plots, low water prices have resulted in production systems using water intensively, with returns on investments below the capital and operating costs of the infrastructure, without generating locally the types of economic spinoffs that may have justified these investments.

Increasing resilience for farmers needs to make financial sense

The agricultural sector does not only suffer the impacts of climate change, but its own practices can be a cause of increased vulnerability. There are practices and measures that can minimize this vulnerability, including:

- regenerative agriculture
- hydrological-forestry restoration in areas at high risk of erosion
- promotion of native forest crops to replace agricultural crops in flood-prone areas
- crop rotation and diversification
- maintenance of vegetation covers and the incorporation of pruning remains into the soil for woody crops
- saving and efficiency measures aimed at reducing net water consumption
- a commitment to crop varieties or livestock species that are better adapted to the impacts of climate change.

Promoting these practices requires financial incentives in irrigation planning as well as coordination of agricultural policy and hydrological planning. Some of these practices and measures have double benefits for climate change mitigation and adaptation: fixing CO_2 and acting as agricultural sinks. In Spain they have been included in the National Common Agricultural Policy Plan and in the National Integrated Energy and Climate Plan (2021–2030) together with other measures that promote the reduction of GHG emissions.

Conclusions

Water security has always been a defining challenge for Spanish economic progress. Perceptions of water security issues may have changed with time, from guaranteeing a minimum supply of water with the little resources available in the past to increasingly being able to respond to the irreducible uncertainties brought by climate change over future water supplies.

Many lessons can be learned from a century of water supporting economic progress in a country where water security has been a fundamental challenge. These lessons are relevant for providing new and more resilient responses to the emerging challenges of adapting to climate change while curbing the detrimental trends inherited from traditional water development and use. The ability to move towards a water-resilient economy and better respond to increased climate risk — a clear national economic and social priority given the water policy challenges — is determined by the ability to act and plan collectively.

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PART 3

Enabling Economic Resilience: Seven Modes

Mode 1: Intra- and cross-sectoral planning can define economy-wide resilience priorities

While both public and private sectors have critical roles to play around economic resilience, articulating a vision of the goals and strategies for economic resilience almost certainly must come from the public sector and major public finance, investment, and regulatory bodies. For many countries, transboundary resource sharing is a critical consideration as well.

1. Assess and evaluate the intrinsic relationship between economic growth and water consumption and explore strategies for decoupling them[1]. Ideally, the assessment should be quantitative, but many economic growth policies may only have indirect and implicit links to water use.
    a. Include both direct (e.g., irrigation) and virtual (e.g., energy, manufacturing) water consumption in estimates of economic growth.
    b. Stress-test water commitments for a variety of climate and non-climate stressors across economic sectors and identify synergies and tradeoffs (e.g., energy vs agriculture).
    c. Set variable targets for water use according to expected limitations and needs for river basin closure in specific territories. Promote activities with flexible operating rules to adjust water use according to resource variability, economic value, sustainability, or level of competition.
    d. Avoid the assumption that water use efficiency is fully aligned with adaptation and resilience. For example, Jevon's paradox shows how improvements in technical efficiency in irrigation water systems often lead to net increases in water use, especially if the costs associated with delivery or consumption fall with increased efficiency.
    e. Identify water-climate connections from a macroeconomic perspective, including key supply chains and in relation to trade.
2. Water valuation systems may need to follow stepped systems, such as for increasingly scarce or severe droughts. They should also plan for events that have not yet been experienced.
    a. Consider multiple futures, including quite different credible extreme scenarios, for long-term planning.
    b. Plan for diversity of water sourcing, including unconventional sources such as water recycling.
    c. Plan for water source redundancy for critical infrastructure systems.

[1] Decoupling environmental pressure from economic growth refers to breaking the link between "environmental bad" and "economic goods." It occurs when the growth rate of an environmental pressure is less than that of its economic driving force (e.g., GDP) over a given period (Ruffing, 2007).

   d. Incentivize redundancy and diversity in vital water-sensitive sectors, especially those that depend on long-lived infrastructure (e.g., water and energy utilities). Older systems, for instance, may be optimized for past or disappearing climate regimes.

3. Manage for reorganization.
   a. Resilience systems need to assess the distributional impacts with direct support to the disadvantaged.
   b. Resilience systems will require a shift in institutions, policies and regulatory frameworks.

Case Study: Decoupling Water Consumption From Economic Growth
The Third National Water Master Plan (NWMP-3) implemented by Jordan and GIZ exemplifies decoupling water consumption from economic growth. It incorporates all critical factors impacting water consumption, including future projections and their impact on water supply security, thus addressing overall economic and social resilience. NWMP-3 integrates climate change impacts into strategic planning and details the analysis of water supply and demand at the municipal level, which identifies demand gaps and guides evidence-based strategic investments in the water sector. The utilization of treated wastewater programs has not only enhanced water resilience but also economic resilience, specifically in the areas of food security and employment. Increasing water availability can contribute to food and water price reduction, and create opportunities for small-scale farmers. The agricultural sector is most susceptible to changes in water availability currently, reusing 91% of treated wastewater, which accounts for 15% of total water resources in 2020.

Mode 2: Resilience governance frameworks can ensure that water tradeoffs are transparent and clear, enabling decision-makers and stakeholders to anticipate rather than simply react to risks

Government expenditures and revenues are both affected by climate-water risks, which can manifest as both explicit and implicit contingent liabilities (OECD, 2022). Resilience governance frameworks provide policymakers with systematic approaches to assess and proactively address risks and evaluate tradeoffs.

1. Resilience requires shifts in how institutions operate, how policies are defined and implemented, and how regulatory frameworks incentivize and limit actions. Explicit consideration of water sharing and allocation is an essential tool among decision-makers in finance, agriculture, food processing, manufacturing, energy, and data.
2. Volumetric agreements and regulatory systems can be brittle during climate transitions; non-volumetric agreements may be more useful and functional in high variability systems.
3. Water scarcity / drought programs should be staged for severity and intensity, should identify protected groups, ecosystems, and sectors, and should be revised regularly to incentivize adjustment to evolving extreme events.

4. Resilience systems need to assess the distributional impacts with direct consideration of both current equity and justice issues as well as how climate shifts may alter equity over time. For instance, flood risk may be increasing for less wealthy communities or water scarcity may place a higher burden on women and girls for WASH.

Case Study: Coordinating Across Investment Stakeholders
Afghanistan, a country with ongoing political instability, faces severe water scarcity due to climate change, conflict, and poor institutional management. Despite receiving over US$ 4 billion in ODA financing over the last 20 years, Afghanistan still requires a significant investment of more than 6% of its GDP to address flood risks. The investment gaps are significant, and the recent Taliban takeover has exacerbated the humanitarian crisis in the country. To achieve economic resilience via water resilience (under the de facto authorities), the international community, especially bilateral and multilateral donors, must coordinate a comprehensive approach that addresses the root causes of water insecurity and economic fragility in the country. The fastest path could be creating an Afghanistan Water and Climate Emergency Working Group and an Afghanistan Water and Climate Emergency Fund under the Special Trust Fund for Afghanistan (STFA) by the United Nations. Creating a dedicated setup to centralize and ring-fence finance would provide proper focus and attention to Afghanistan's water and climate change emergency.

Mode 3: Economic analytical tools and incentives can guide technical decision makers to see water beyond individual sectors and projects and integrate resilience early

1. Measure the total economic value of water, its contribution to different sectors in the economy, and the sensitivity of the economy to disruptions in water.
2. Adapt national macroeconomic models, general equilibrium models, and balance of trade prospects to incorporate water uncertainty, dynamic hydrology, and risk assessments. This includes developing an interface between microeconomic models of water use.
3. Use incentives.
    a. Create incentives to protect and conserve existing resources.
    b. Pricing schemes for water services can serve as incentives to promote water resilience, including through the protection of resources, the implementation of nature-based solutions, and the full use of non-conventional water supplies.
    c. Use subsidies wisely. Getting subsidies right is essential to ensure that investments in redundancy (for example) do not lead to increasing demands, promote greater resilience, and ensure equity.
4. Cost-benefit analysis should consider co-benefits, which can also extend to non-quantitative co-benefits.
5. Discount rates should reflect risk sharing, future uncertainty, and long-term benefits.
6. Aligning operational lifetimes with financing periods can help reflect long-term risk sharing with lenders and investors and incentivize long-term risk assessment.

7. Use incentivization and pricing schemes to encourage robustness to high-confidence climate impacts as well as flexibility for impactful but uncertain impacts.

Mode 4: Tailored finance can help pay for the additional costs of adaptation and resilience, while resilient regulatory frameworks can make climate-water risks visible to investors and the public

Water resilience projects have received at most 5% of all labeled climate finance (OECD, 2021). Leveraging climate finance mechanisms to ensure that all water investments incorporate de-risking and resilience components is essential for scaling.

1. Results and performance based financing can incentivize the incorporation of resilience in planning, regulation, investment design, and operations — including the need to shift investment strategy if unexpected conditions arise.
2. Financial systems should undergo climate and non-climatic stress tests (e.g., credit institutions and reinsurance companies and programs).
3. Diversify insurance systems to reflect a variety of climate impacts, stresses, and shocks (e.g., fast-access insurance pools, parametric insurance for pre-determined thresholds/impacts).
4. Regularly update risk pools, risk sharing, and insurance and credit rates to anticipate plausible future impacts.
5. Negotiate with commercial credit institutions and insurance and reinsurance programs to ensure they stay in place and can facilitate adjustments of economic activities to emerging conditions.
6. Undeveloped or open space land and protected areas can have critical flood buffering and groundwater recharge value not reflected in real estate valuations, zoning, or planning processes

Case Study: Financing Redundant, Expanded Water Supply Systems

The case of Namibia's capital, Windhoek, highlights the country's vulnerability to climate change, particularly regarding water availability. To address this, a Managed Aquifer Recharge (MAR) project was implemented in 2006 as the most cost-efficient option compared to other alternatives. The MAR scheme serves as a supply backstop to ensure water supply during prolonged droughts. Its integration with alternative water supply options offers an excellent opportunity for investors to realize attractive returns while contributing to the city's water security and resilience. For instance, it can yield an economic internal rate of return (IRR) of approximately 94%, while the integration with the Okavango River transfer scheme can yield an IRR of around 68%. Incorporating resilience in planning, investment design, and operations can be incentivized through results and performance-based financing, which may require a shift in investment strategy in response to unexpected conditions. To allow for future operation of the scheme, it is expected that the beneficiaries co-finance the operation over the economic lifespan of the project with US$ 115 million for operational costs and capital replacement over 30 years. This can be done via water expenses, which can be adopted according to the amount and usage.

Mode 5: Enhancing tools for evaluating resilience can communicate efficacy and progress, and distinguish resilience from business as usual approaches

1. Define resilience as a measurable concept with publicly available indicators in order to inform all stakeholders about how the system is evolving.
2. Water quantity and quality are not direct measures of water resilience.
3. The updating of financial and economic regulations and incentives should be managed by independent groups to ensure equity, transparency, and underrepresented groups (e.g., the poor, indigenous groups, ecosystems).
4. The integrity of natural hydrological systems is important to value explicitly for infrastructure systems, including the use of governance, regulatory, policy, and legal agreements that allow for the formal integration of these systems as a public good (e.g., Peru's new NBS laws).

Case Study: Facilitating Private Sector Investment in Water Resilience to Meet Public Sector Goals

In the 1980s, Chile implemented free-market economic changes privatizing the country's water and sanitation services. As a result, private entities are now responsible for delivering these vital services to the public. Privatization has brought numerous benefits to the water sector in Chile, including increased efficiency, investment, and improved services for customers. Private companies have the incentive to provide high-quality services to remain competitive and profitable, leading to better infrastructure, water quality, and service reliability. They invested US$ 2.3 billion in wastewater treatment between 2000 and 2017, enabling Chile to achieve treatment levels comparable to advanced countries. The success of the wastewater treatment plan can be attributed to several measures, such as a regulatory framework that allowed private capital in the sector. The Chilean private sector's role in promoting water resilience goes beyond providing water-related services. It includes assuming responsibility and leadership for responsible investment that prioritizes sustainability and environmental protection. Also, it includes improving the efficiency of water resources and communicating responsible use protocols to their consumers. This demonstrates a success case for updating financial and economic regulations and incentives that enable a conducive environment.

Mode 6: Investing in capacity and training can create durable, permanent institutional changes and fuel a reorientation towards resilience

1. Identify eco-hydrological "transition costs" for communities, work categories, and livelihoods that will be sensitive to water change.
2. Conduct training and outreach for climate-adjusted industries (e.g., resilience extension services to enable broader food system resilience).

Case Study: Diversifying Existing Livelihoods, Organizing Institutions and Infrastructure to Work with Rather than Against Flow Regimes

Wetland systems, such as the Inner Niger Delta (IND), have significant economic and social value at local and national levels in the Sahel. The economy of the IND is based on farming, fishing, and pastoralism, and it supports a diverse range of livelihood strategies, including seasonal migration. The annual cycle of flooding and de-flooding is a critical feature of the IND's regional economy, which requires new water infrastructure to be "conflict sensitive" (Wetlands International, 2019). The current strategy in the IND primarily focuses on large-scale irrigation and hydropower, which will bring benefits but also risks, including changes in the flood pulse, diminished livelihoods, biodiversity loss, and increased instability. Therefore, safeguarding and optimizing the role of the IND should be central in future planning and investment. Measures are needed to ensure that water-related investment, strategy, and policy maintain critical natural systems as part of development solutions, rather than risking depletion and creating risks and problems. Climate change is disrupting current practices and requires new strategies to increase food and energy production and ensure water security. A holistic, ecosystem based, and human rights oriented approach to water management of the IND, along with improving irrigation efficiency and using less water-intensive crops, could support Mali's development and food security ambitions and provide a lifeline to the people in the IND. The existing culture of diversity in livelihood strategies is the basis for an adaptive, flexible coping mechanism that can also be expanded to encourage both resilience and prosperity for the future. Currently, there is limited consultation on such initiatives in Mali, and environmental impact assessments do not expose the full range of issues and implications to the economy and society as a whole.

Mode 7: Risk identification and reduction procedures can make water-based resilience a consistent, reliable outcome

1. Mainstream early phase project-level climate risk assessments that can take account of uncertainties in the water cycle.
2. Analyze the water distribution system, not just the hydrological basin, for water risk and change.
3. Consider critical sector water-climate interactions, such as tradeoffs around water.
4. Chains of actions, supplies, processes may contain significant water risks beyond just direct physical facility risks.
5. Stress tests are a powerful tool to explore impacts and interactions across a wide range of climate conditions early in the development cycle to prepare for hidden water-related systemic threats (e.g., ultra-pure water in Taiwan's semiconductors).
6. Develop and plan for diversity of water sources, including unconventional sources.
7. Flexibility can be cost-effective as a form of infrastructure and investment planning in the context of climate and non-climatic uncertainties.
8. Consider multiple futures, including quite different credible extremes, for long-term planning.

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